LAMONT GEOLOGICAL OBSERVATORY
COLUMBIA UNIVERSITY
PALISADES, NEW YORK

PRECISION SOUND VELOCITY PROFILES IN THE OCEAN

VOLUME II

THE SOUND CHANNEL IN THE BERMUDA-BARBADOS REGION
April - July
(1964)

by

Ants T. Piip
Columbia University Geophysical Field Station
St. David's, Bermuda

Technical Report No. 4
CU-4-67

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June 1967

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ABSTRACT

A collection of consecutive, detailed sound velocity profiles from 20 stations in the Bermuda-Barbados-Puerto Rico area is presented together with composite profile envelopes of sound velocity, and temperature for each station. These stations were taken during the months of April to July. The report emphasizes the variability of the sound channel, and its dependence on geographical location. A number of cell-like water masses, differing from the norm at the site, are pointed out. Since a number of stations included in this report were taken at sites investigated during a cruise 4 months earlier, a comparison of the sound channel parameters for November-December and April-May is included. The 4-month changes at these sites are found to be of about the same order of magnitude as short-term variations over each station alone.

This report is a direct sequel to VOLUME I of this series.

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INTRODUCTION

This report describes the sound channel in an area bounded roughly by Bermuda, 15°North 55°West, Barbados and Puerto Rico during the months of March to July. It is a sequel to Volume I of this series (Piip, 1966), which covered the same region in November and December. Included in this report are detailed, consecutive precision sound velocity profiles; their composite envelopes showing the total variability during each station; and temperature profile envelopes obtained at each station on cruise 106 of our R/V SIR HORACE LAMB. Stations 35-39 were taken on board the R/V ROBERT D. CONRAD during their cruise #8.

We were interested in several aspects of the variability in the sound channel region. We chose and organized our stations accordingly, to yield information about the following:

(1) Short term variations at the same site: repeated consecutive profiles at each station.

(2) Long term variations at the same site: Stations repeated at the same site at longer intervals, of the order of weeks. Several of the stations included in the present report were taken at sites identical to some of the stations of the earlier cruise, about 4 months earlier.

(3) Dependence on geographical location: Stations a short time apart, at different sites.

This report and the profiles are intended primarily as source material and as an illustration of the variability in the sound channel region. Therefore, no analysis or biography and hardly any discussion is included, except a barest outline.

INSTRUMENTATION, DATA PROCESSING

The instrumentation used in obtaining data for this report was the same as during our November-December cruise in this area, and has been described elsewhere (Piip 1964, 1966), except for the addition of a FM-telemetering deep-sea thermometer (Hytech model 4002). As before, two velocimeters were used side-by-side.

Depths were measured by means of a precision pressure gauge, periodically calibrated against an upside-down echosounder. Data from all 4 channels, (pressure gauge, velocimeter 1, velocimeter 2, thermometer), and 10-minute time marks were printed on paper tape at the recording station on the ship for further data reduction ashore.

Data reduction was performed by computer. The velocimeter, thermometer and pressure gauge readings were validated and converted to velocities in meters per second (m/s), temperature (^{o}C) and depths in meters (m). For each velocimeter and thermometer reading, the average depth from the two pressure gauge readings immediately before and after was assigned. The velocity, temperature and depth values thus obtained were plotted on a CalComp plotter. A numerical printout of these values, and output data cards were obtained at the same time.

The final sound velocity plots are visual averages of the two nearly coincident traces of the computer output. Only these profiles have been used where the two velocimeter traces were tracking and in good agreement; or if one velocimeter was performing erratically (not often!), data from the other instrument was used if there was no question about its proper operation and calibration.

The computer program for this data reduction was written by Dr. James Dorman of Lamont Geological Observatory.

ACCURACY AND CORRECTIONS TO THE PLOTS

The estimated accuracy of the sound velocities in the plots presented herewith is ±20 cm/sec, precision about ±10 cm/sec. The velocities given in the plots pertain to a velocimeter standardized for +10°C. In order to obtain the true sound velocity at other ambient temperatures, corrections have to be applied to the values given in the plots, because of the thermal expansion of the instrument. The corrections are given in the following table.

True sound velocity = + Correction

Correction = $1.46 \cdot 10^{-5}$ $(T - 10)$ V_i

where T - ambient temperature, °C.

V_i - indicated sound velocity.

T, °C	Correction, m/s
30	+0.44
25	+0.33
20	+0.22
15	+0.11
10	±0.00
5	-0.11

All sound velocities are based on Greenspan & Tschiegg (1957), whose tables for distilled water were used in our instrument calibrations in the laboratory.

Depths are accurate to ±10 meters, and are equivalent to uncorrected acoustic depths on a 1463 m/s (4800 feet/s) machine. To obtain true depths, corrections shown in Fig. 2 should be added to the indicated values.

Temperatures are good to ±0.05°C.

Positions are average positions of the ship at each station, as determined by classical navigation methods. At station, the ship was hove to.

ORGANIZATION AND EXPLANATION OF PLOTS

Figure 1 is a chart of the stations included in this report.

Profiles from the stations are presented in numerical (or chronological) order, in three different forms. In each case, the scale factors have been chosen to make the profiles easily readable by means of a transparent overlay of standard 10 x 10 to the inch (or mm) graph paper. For figures 3 - 6, and temperatures, a 1/8 inch grid will be found more practical.

Figures 3 - 6 form a catalogue of the stations. These small figures are the composites of the first and last profiles at each station, both of sound velocity and temperature, and reach from the surface to the maximum depth of measurement.

It should be pointed out that the "wiggles" in the temperature and sound velocity profiles are not commensurate with each other: The temperature scale is compressed by a factor of approximately 3 ($1^{\circ}C$ change in temperature causes a change in sound velocity by about 3.6 m/s).

In a few cases, Stations 26 and 28, the thermometer was inoperative during part of the station. The temperature envelopes therefore do not cover the same time interval as the sound velocity ones: the temperatures include profiles 26/1 - 26/9 and 28/3 - 28/6, whereas the velocities are made up of 26/1 - 26/12 and 28/1 - 28/6. There is no temperature for station 27.

Figures 7 - 27, consecutive sound velocity profiles for each station, are intended for analysis of short-time variability in the vicinity of the sound channel.

The profiles have been separated by 2 m/s. A double gap, 4 m/s between profiles, indicates they are not quite consecutive, but are separated by a longer interval. Each profile is numbered and carries identifying marks at round velocity values, 1495 m/s, etc. The small horizontal ticks are 10-minute time marks. Their depths and times for each profile are listed in the Appendix.

We did try to control profiling winch speed to give a complete instru-

ment reading sequence about every 10 meters, or a sampling length of about 2 meters, in depth for each instrument. As can be seen from several of our profiles, we were not fully successful in this at all times. E.g., the last two profiles of station 31 (31/5 and 31/6, shown dotted) were taken at too fast a rate and have lost most of their fine structure and detail.

Figures 28 - 50 are composite envelopes of all profiles of the sound channel region at each station. Sound velocity is at right, temperature at left. Each figure carries a note giving the duration and number of profiles of the station.

We consider this presentation most useful in estimating the total expected variability at each site, and identifying the most unstable depths and/or sites. In acoustics, an estimate of the expected propagation uncertainties can be made. Hydrologically, stable and unstable water regions can be identified with ease.

RESULTS

General

The general shape of the profiles around the sound channel, and at depth, does not differ appreciably from those obtained in the same areas 4 months earlier.

We still have two major regions of different characteristics:

North of 20°N is an open ocean, undisturbed by major currents. The only prominent discontinuity in this region is the southern boundary of the Sargasso Sea or 18° water, but even this subtropical convergence is quite smooth and gradual. The 18° water slowly disappears between about 27°N and 23°N (Stations 20, 21).

As a consequence of these rather quiet waters, the sound velocity profiles are quite smooth ("classical"), and show little variation over the duration of each station. Most of the short-time variations in this region seem

to be caused by oscillations of the thermocline, (i.e., internal waves) with an occasional cell of strange waters here and there. Very little layering is observable. The sound channel in this region lies at 1000-1100 m depth, the minimum sound velocity being around 1491-92 m/s.

South of 20°N the sound channel lies appreciable shallower, at depths ranging from 700 to 1000 m, approximately. Because of the shallower depth of the sound channel, the minimum sound velocities are lower, too - between 1485 and 1490 m/s.

The region around Anegada Passage (Stations 33, 34, 38) is somewhat abnormal in its sound channel parameters: the axis depth and velocity are closer to the northerly region than to other locations at the same latitudes.

Most of our stations south of 20°N were taken within a few hundred miles of the Antillean islands, in an area with a very complex current and water structure: the Carib current, the several in- and outflows through various passages between the islands; and at sound channel depth, the Sub-Antarctic intermediate waters close to the end of their northerly movement and mixing with other, local water masses. Consequently, the profiles in this area are very variable and show extensive layering and numerous cells of strange waters.

In general, the sound channel in this area is rather pointed and narrow.

Stations 24 and 25, more than 200 miles east of the islands, again show a sound channel characteristic of an open ocean: smooth profiles, and rather stable.

The sound channel in April-May compared to November-December, at identical, selected sites.

Table I is an attempt to compare the sound channel parameters from our November-December 1963 cruise to these of the April-May 1964, at a number of sites that were investigated during both cruises.

The left-hand side of the table contains parameters for November- Decem-

ber, the right-hand those of April and May. All stations in the same horizontal blocks were taken at the same site, within a few miles of each other. Approximate positions for each site are given in parentheses, in the right-hand side of the table.

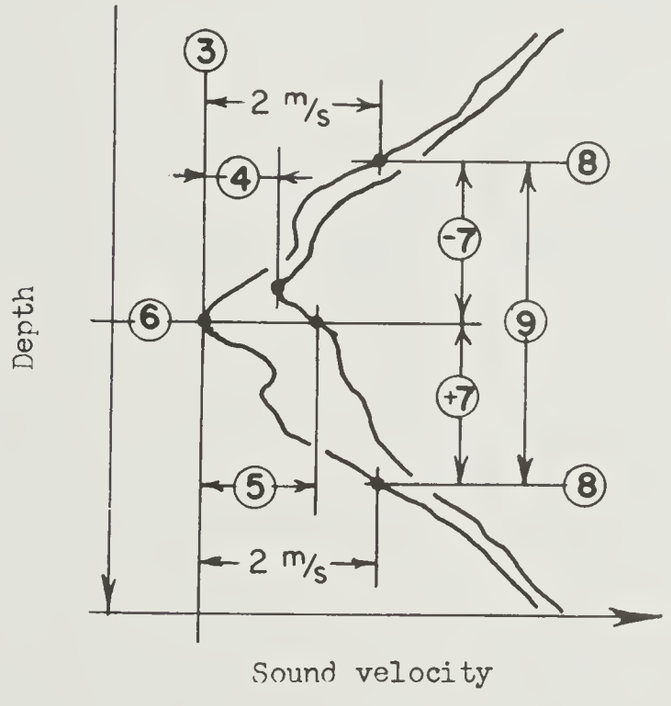
The table is based on readings obtained from the composite envelopes of all sound velocity profiles at each station.

. . .

The columns have the following meanings (see sketch; numbers in circles are column headings):

Column 1: Station number

Column 2: Mean sound velocity at 1500 m depth.



Column 3: The axis or minimum minimum sound velocity is the lowest velocity in the composite profile envelope.

Column 4: The sound channel width is defined as the difference of the minima of the high-velocity (right-hand) and low-velocity

(left-hand) contours of the composite envelope. These minima do not necessarily occur at the same depth, they can be separated by several hundred meters.

Column 5: Variability at the sound channel axis. Defined as the width of the composite envelope at the depth of the min. min. velocity.

Column 6: Axis depth: The depth at which the min. min. sound velocity occurs.

For columns 7, 8, 9 we have arbitrarily defined the sound channel as the region between points on the low-velocity (left-hand) side of the composite envelopes, having a sound velocity 2 m/s higher than the min. min. velocity.

Column 7: Vertical spread of the upper and lower boundaries of the sound channel, up and down from the min. min. velocity (axis) depth.

Column 8: Depths of the upper and lower boundaries of the sound channel.

Column 9: Total vertical extent of the sound channel.

Column 10: Duration of station, hours.

. . .

The table shows that most of the changes that have occurred over 4 months at these sites are of the same order of magnitude as the short-time variability during each station alone.

There are, however, certain conspicuous changes that are due to the change of the season; changes that are larger than can be explained by measuring uncertainties or short-time variations.

Table II lists these 4-month changes qualitatively. Column headings are the same as in the first table, a "+" indicates a definite increase in the parameter from November-December to April-May, a "-" indicates a definite decrease. Blanks indicate no definite change.

TABLE I

SOUND CHANNEL PARAMETERS AT IDENTICAL SITES, IN NOVEMBER-DECEMBER AND APRIL-MAY

(Based on sound velocity profile envelopes)

NOVEMBER-DECEMBER, 1963

1	2	3	4	5	6	7	8	9	10
Station number	Mean sound velocity at 1500 m depth	Axis (min. min.) sound velocity	Sound channel width (min.max. - min.min.)	Variability at axis depth	Axis (min. min. s.v.) depth	between points: axis s.v.+2m/s, low s.v. side of envelope: S. channel spread, up & down from axis	between points: axis s.v.+2m/s, low s.v. side of envelope: Sound channel depth limits	Vertical extent of sound channel	Station duration
#	m/s	m/s	m/s	m/s	m	m	m	m	h
1	1494.2	1491.5	0.6	0.8	1160	-250 +270	910 1430	520	12
17	94.6	91.2	0.3	0.3	1090	-140 +340	950 1430	480	2
3	93.7	91.2	1.0	1.5	1050	-250 +410	800 1460	660	17
16	93.5	91.4	0.3	0.6	1200	-380 +300	820 1500	680	5
4	93.2	87.2	0.9	2.0	870	- 80 +130	790 1000	210	15
14	93.3	88.7	-	-	960	-200 + 80	760 1040	280	2
5	93.5	89.2	0.3	0.8	850	-110 +280	740 1130	390	4
9	93.7	87.2	0.8	1.3	840	-150 +120	690 960	270	11
15	93.1	88.2	1.7	2.7	810	- 90 +150	720 980	260	8
6	94.0	87.1	1.9	3.1	850	-210 +140	640 990	350	15
8	93.9	89.2	0.9	1.6	820	- 80 +260	740 1100	360	5
7	93.9	86.2	0.7	1.2	800	-200 +170	600 970	370 (Note 2)	12
11	92.8	85.6	1.9	2.4	830	-200 +110	630 940	310	17
12	92.9	84.5	0.5	0.8	720	-160 +110	560 830	270	9
13	93.6	84.0	0.3	0.5	750	-190 +130	560 880	320	3
13A	----	83.2	0.4	2.4	680	- 40 +130	640 810	170	2

APRIL-MAY, 1964

1	2	3	4	5	6	7	8	9	10
Station number	Mean sound velocity at 1500 m depth	Axis (min. min.) sound velocity	Sound channel width (min.max. - min.min.)	Variability at axis depth	Axis (min. min. s.v.) depth	between points: axis s.v.+2m/s, low s.v. side of envelope: S. channel spread, up & down from axis	between points: axis s.v.+2m/s, low s.v. side of envelope: Sound channel depth limits	Vertical extent of sound channel	Station duration
#	m/s	m/s	m/s	m/s	m	m	m	m	h
20	1494.3	1491.4	0.8	1.3	1060	-170 +180	890 1240	340	12
(27°N 63°W)									
21	93.4	90.7	0.7	0.8	1120	-220 +200	900 1320	420	10
(23°N 63°W)									
22	93.6	89.3	0.2	0.3	900	-190 +150	710 1050	340	8
32	93.3	87.7	1.6	2.2	830	-130 + 60	700 890	190	6
(18°N 61°W)									
23	93.8	89.0	0.8	0.8	740	- 60 +130	680 870	190	3
31	94.3	88.8	0.7	1.0	760	-110 +320	650 1080	430	8 (Note 1)
(18°N 60°W)									
24	94.3	88.2	0.6	0.8	810	-140 +260	670 1070	400	12
(17°N 58°W)									
25	93.7	87.0	1.0	1.3	850	-230 +160	620 1010	390	8
(16°N 55°W)									
27	93.0	85.8	1.2	2.0	700	-100 +260	600 960	360	12
(13°30N 58°30W)									
28	92.8	86.1	0.9	1.9 2.1	710 820	-60 +80	650 900	250	9 (Note 3)
(14°N 59°30W)									
29B	93.4	84.4	0.4	1.0	740	- 60 +120	680 860	180	3 (Note 4)
(14°15N 60°40W)									
29	----	85.7	0.3	0.5	800	-180 +220	620 1020	400	5 (Note 4)
(14°20N 60°15W)									

Notes: 1) Low velocity cell at 950 m.
2) Low velocity cell at 700 m?
3) Nearly isovelocity 710-820 m.
4) St. Lucia-Martinique channel.

TABLE II

DEFINITE 4-MONTH CHANGES IN TABLE I

Approximate position	1 Station numbers	2 Mean sound velocity at 1500 m depth	3 Axis (min. min.) sound velocity	4 Sound channel width	6 Axis depth	9 Vertical extent of sound channel
27°N 63°W	1,17 - 20			+	-	-
23°N 63°W	3,16 - 21		-			-
18°N 61°W	4,14 - 22,32	+			-	
18°N 60°W	5,9,15 - 23,31	+			-	-
17°N 58°W	6,8 - 24	+		-	-	+
16°N 55°W	7 - 25		+	+	+	+
13°30N 58°30W	11 - 27			-?	-	+
14°N 59°30W	12 - 28		+	+		
14°15N 60°40W	13 - 29B		+?			-
14°20N 60°15W	13A - 29	+	+		+	+

The changes that have occurred over the winter months do not show any clear-cut or systematic pattern over all our stations. Nevertheless, a few trends can be distinguished:

Sound velocity at 1500 m depth (Col.2): noticeable increases only in a sector a few hundred miles out from Antigua, between NE and E.

Axis velocity (Col.3): an increase south of 17°N, a decrease along the southern edge of the Sargasso Sea (18° water).

Sound channel width (Col. 4): indications of an increase in southern waters, except close to Barbados.

Axis depth (Col. 6): a decrease north of 18°N, an increase in the open ocean far east of the Antillean arc.

Vertical extent of sound channel (Col. 9): a decrease north of 18°N, increase in the open ocean far east of the Antillean arc.

The changes in axis depth and axis velocity are reasonably correlated. There also seems to be some correlation between increases in the vertical extent of the sound channel, and channel width, but the evidence is far from conclusive as yet.

Cell-like phenomena, etc.

Our method of taking several detailed, consecutive profiles at each station sometimes shows large bodies of waters, with different properties than the norm at the site, moving around in the ocean. We touched on this phenomenon of "cells" in Volume I of this series. In the present collection, the following stations show prominent examples of cells "developing" or "disappearing":

Station 26: A warm, high-sound velocity cell developing at 500-700 m (Unfortunately, most of this cell is above the top of the individual profiles. The gradual narrowing of the sound channel is quite conspicuous).

Station 27: Radical changes between 1000-1500 m depth. A patchy, large high-sound velocity cell in the offing?

Station 30: A sharp, warm, high sound velocity "notch" at 800 m, disappearing.

Station 32: Sharply defined, warm high sound velocity layers moving upwards in unison, from about 750 to 850 m, and at 900 - 950 m depth.

Station 34: A low sound velocity cell at 700 - 800 m, disappearing. Observe gradual flattening of profiles.

All these stations lie within 200 miles of the Antillean arc. The apparently very high incidence of cells in this region is due to the complicated water structure close to these islands. This would be a good region to find out more about the sizes, motions and history of these cells.

In our stations 29 and 29B, in the middle and the Atlantic side of the St. Lucia - Martinique channel, respectively, we still see indications of the deep countercurrent we postulated in Volume I of this series (at approximately 800 and 900 m in Stn. 29, 920 and 1030 m in Stn. 29B). They are not as conspicuous as they were in December, nor can they be followed as clearly at other sites towards Barbados as before. It seems as if the countercurrent jet were getting patchy, or better mixed, in springtime. Could it be a seasonal phenomenon? At least, it is a semi-permanent feature.

ACKNOWLEDGEMENTS

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Thanks are due to my colleagues and collaborators at the Columbia University Geophysical Field Station, particularly Brian Turner, and Capt. McCann and the crew of our R/V SIR HORACE LAMB.

Dr. James Dorman's contributions to this program are gratefully acknowledged: he wrote the data reduction programs for the LGO computer, and spent several nights helping out in producing the plots.

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LIST OF STATIONS

Station 19	30°40 N	64°21 W	12 Apr. 1964
20	27°04 N	63°24 W	13/14 " "
21	23°10 N	62°24 W	15 " "
22	18°05 N	61°07 W	16/17 " "
23	18°13 N	59°38 W	20 " "
24	16°50 N	58°07 W	21 " "
25	15°47 N	55°10 W	22/23 " "
26	15°00 N	59°00 W	24/25 " "
27	13°30 N	58°30 W	25/26 " "
28	13°59 N	59°31 W	29/30 " "
29	14°17 N	60°49 W	30 " "
29A	14°16 N	61°03 W	30 " "
29B	14°15 N	60°36 W	1 May 1964
30	16°00 N	60°00 W	1 " "
31	18°16 N	59°41 W	2 " "
32	18°07 N	61°11 W	3 " "
33	18°36 N	62°11 W	4 " "
34	18°46 N	63°30 W	4 " "
35	15°22 N	61°04 W	7 July 1964
36	15°05 N	61°14 W	8 " "
37	14°18 N	60°55 W	12 " "
38	18°22 N	64°16 W	15 " "
39	20°06 N	64°15 W	21 " "

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APPENDIX

Depth and timing of stations and profiles

Profile	D(m)	GMT	Profile	D(m)	GMT	Profiles	D(m)	GMT	Profile	D(m)	GMT
19/1	29	1220	20/1	338	1950	20/9	839	0400	21/4	1878	1030
	412	1230		530	2000		1332	0410		1677	1040
	670	1240		817	2010		1690	0420		1257	1050
	919	1250		1045	2020		1933	0430		682	1100
	1049	1300		1215	2030	20/10	1983	0440	21/5	705	1110
	1260	1310		1384	2040		1770	0450		1023	1120
	1493	1320		1708	2050		1551	0500		1372	1130
	1710	1330	20/2	1813	2110		1321	0510		1716	1140
	1840	1340		1700	2120		982	0520	21/6	1733	1200
19/2	1609	1400		1515	2130	20/11	619	0530		1371	1210
	1540	1410		1350	2140		791	0540		944	1220
	1457	1420		1090	2150		1158	0550	21/7	884	1240
	1335	1430		1001	2200		1507	0600		1424	1250
	1169	1440		681	2210		1762	0610		1735	1300
	929	1450	20/3	671	2220		1979	0620	21/8	1723	1320
	560	1500		929	2230	20/12	1756	0630		1885	1330
19/3	648	1510		1150	2240		1507	0640		930	1340
	899	1520		1541	2250		1255	0650	21/9	662	1350
	1189	1530		1913	2300		925	0700		913	1400
	1382	1540	20/4	1881	2310		615	0710		1177	1410
	1574	1550		1562	2320		88	0720		1440	1420
	1745	1600		1278	2330					1663	1430
19/4	1764	1610		960	2340	21/1	4	0620		1781	1440
	1442	1620		659	2350		119	0630		1888	1450
	1111	1630	20/5	678	2400		345	0640	21/10	1944	1500
	829	1640		925	0010		538	0650		1690	1510
19/5	629	1650		1143	0020		700	0700		1471	1520
	984	1700		1340	0030		827	0710		1283	1530
	1265	1710		1529	0040		990	0720		1057	1540
	1685	1720		1788	0050		1132	0730		841	1550
19/6	1732	1730	20/6	1837	0110		1303	0740		516	1600
	1279	1740		1621	0120		1521	0750			
	747	1750		1300	0130		1674	0800	22/1	20	2140
19/7	761	1800		996	0140	21/2	1954	0810		108	2150
	1348	1810		725	0150		1840	0820		258	2200
	1758	1820	20/7	672	0200		1656	0830		403	2210
19/8	1742	1830		827	0210		1484	0840		430	2220
	1477	1840		1077	0220		1215	0850		483	2230
	1195	1850		1291	0230		915	0900		559	2240
	905	1900		1424	0240		680	0910		657	2250
19/9	960	1920		1630	0250	21/3	747	0920		709	2300
	1512	1930		1793	0300		961	0930		790	2310
19/10	1645	1950	20/8	1976	0310		1238	0940		861	2320
	1460	2000		1771	0320		1491	0950		953	2330
	1039	2010		1481	0330		1701	1000		1009	2340
	565	2020		1112	0340		1862	1010		1071	2350
	97	2030		701	0350					1137	2400

Profile	D(m)	GMT
22/1	1176	0010
(cont'd)	1207	0020
	1232	0030
	1312	0040
	1518	0050
	1675	0100
	1838	0110
22/2	1827	0130
	1659	0140
	1548	0150
	1265	0200
	951	0210
	922	0220
	689	0230
22/3	823	0250
	981	0300
	1098	0310
	1257	0320
	1335	0330
	1510	0340
	1598	0350
	1708	0400
	1900	0410
22/4	1975	0420
	1769	0430
	1549	0440
	1289	0450
	1054	0500
	806	0510
	497	0520
	88	0530
23/1	234	1030
	536	1040
	871	1050
	1057	1100
	1276	1110
	1523	1120
	1710	1130
	1922	1140
23/2	1803	1200
	1482	1210
	1203	1220
	979	1230
	803	1240
	582	1250
	342	1300
24/1	96	0620
	292	0630
	528	0640
	758	0650
	932	0700
	1072	0710
	1206	0720
24/1	1320	0730
	1600	0740
	1719	0750
	1880	0800
24/2	1661	0820
	1524	0830
	1290	0840
	1047	0850
	900	0900
	705	0910
24/3	561	0920
	721	0930
	877	0940
	1047	0950
	1188	1000
	1321	1010
	1542	1020
	1666	1030
	1832	1040
24/4	1941	1050
	1685	1100
	1443	1110
	1173	1120
	934	1130
	651	1140
24/5	730	1150
	895	1200
	1050	1210
	1232	1220
	1455	1230
	1661	1240
	1778	1250
	1901	1300
24/6	1873	1320
	1593	1330
	1283	1340
	915	1350
	592	1400
24/7	728	1410
	922	1420
	1119	1430
	1309	1440
	1377	1450
	1419	1500
	1442	1510
	1481	1520
	1530	1530
	1556	1540
	1570	1550
	1677	1600
	1907	1610
24/8	1739	1630
	1595	1640
	1457	1650
	1279	1700
24/8	1077	1710
	980	1720
	767	1730
	495	1740
	90	1750
25/1	55	1510
	290	1520
	419	1530
	620	1540
	779	1550
	878	1600
	1089	1610
	1280	1620
	1445	1630
	1579	1640
	1712	1650
	1835	1700
	1930	1710
25/2	1951	1730
	1770	1740
	1634	1750
	1482	1800
	1290	1810
	1130	1820
	1108	1830
	853	1840
25/3	720	1900
	893	1910
	1058	1920
	1187	1930
	1387	1940
	1556	1950
	1683	2000
	1810	2010
25/4	1797	2030
	1720	2040
	1665	2050
	1644	2100
	1433	2110
	1296	2120
	1156	2130
	978	2140
	780	2150
	613	2200
	292	2210
25/5	15	0700
	495	0710
	656	0720
	865	0730
	976	0740
	1097	0750
	1185	0800
	1335	0810
	1571	0820
	1706	0830
	1874	0840
25/6	1783	0900
	1631	0910
	1403	0920
	1282	0930
	1120	0940
	866	0950
25/7	711	1010
	945	1020
	1142	1030
	1349	1040
	1542	1050
	1765	1100
	1947	1110
25/8	1881	1120
	1647	1130
	1363	1140
	1154	1150
	1017	1200
	783	1210
	563	1220
	182	1230
25/9	60	2020
	575	2030
	820	2040
	1053	2050
	1303	2100
	1522	2110
	1707	2120
	1811	2130
25/10	1809	2150
	1609	2200
	1354	2210
	1154	2220
	866	2230
	614	2240
	215	2250
26/1	36	2020
	396	2030
	619	2040
	837	2050
	1074	2100
	1140	2110
	1343	2120
	1532	2130
	1571	2140
	1717	2150
26/2	1856	2210
	1579	2220
	1423	2230
	1237	2240
	1024	2250
	831	2300

Profile	D(m)	GMT
26/3	773	2320
	907	2330
	1072	2340
	1279	2350
	1502	2400
	1594	0010
	1707	0020
	1843	0030
	1947	0040
26/4	1933	0050
	1697	0100
	1540	0110
	1193	0120
	927	0130
26/5	80	0150
	987	0200
	1163	0210
	1351	0220
	1533	0230
	1683	0240
	1846	0250
	1947	0300
26/6	1873	0310
	1606	0320
	1323	0330
	1019	0340
	663	0350
26/7	753	0400
	1023	0410
	1313	0420
	1583	0430
	1805	0440
26/8	1885	0500
	1641	0510
	1295	0520
	993	0530
	763	0540
26/9	667	0550
	943	0600
	1175	0610
	1333	0620
	1513	0630
	1793	0640
26/10	1786	0700
	1523	0710
	1327	0720
	1023	0730
	783	0740
	523	0750
	93	0800
27/1	41	1620
	421	1630
	665	1640
	839	1650
	1067	1700

Profile	D(m)	GMT
27/1	1256	1710
	1397	1720
	1567	1730
	1679	1740
	1861	1750
27/2	1719	1810
	1491	1820
	1237	1830
	965	1840
	716	1850
27/3	956	1910
	1138	1920
	1302	1930
	1452	1940
	1549	1950
	1698	2000
27/4	1806	2030
	1751	2040
	1428	2050
	1070	2100
	713	2110
27/5	738	2120
	1057	2130
	1339	2140
	1642	2150
	1926	2200
27/6	1894	2210
	1591	2220
	1460	2230
	1070	2240
	641	2250
27/7	725	2300
	993	2310
	1272	2320
	1557	2330
	1837	2340
27/8	1958	2350
	1673	2400
	1272	0010
	762	0020
27/9	697	0030
	937	0040
	1190	0050
	1433	0100
	1616	0110
	1755	0120
	1885	0130
27/10	1598	0150
	1217	0200
	803	0210
27/11	679	0220
	913	0230
	1180	0240
	1410	0250
	1609	0300
	1763	0310
	1909	0320

Profiles	D(m)	GMT
27/12	1912	0330
	1649	0340
	1354	0350
	1111	0400
	792	0410
	478	0420
	0	0430
28/1	124	1710
	291	1720
	430	1730
	593	1740
	670	1750
	807	1800
	855	1810
	925	1820
	1151	1830
	1228	1840
	1332	1850
	1539	1900
	1671	1910
	1829	1920
28/2	1669	1940
	1387	1950
	1191	2000
	974	2010
	794	2020
	562	2030
	230	2040
28/3	300	2110
	744	2120
	1184	2130
	1439	2140
	1651	2150
28/4	1630	2210
	1431	2220
	1169	2230
	875	2240
28/5	633	2250
	911	2300
	1169	2310
	1504	2320
	1769	2330
28/6	1775	2340
	1450	2350
	1407	2400
	1402	0010
	1390	0020
	1322	0030
	980	0040
	767	0050
	537	0100
	313	0110
	176	0120
	25	0130

Profile	D(m)	GMT
29/1	3	1500
	244	1510
	384	1520
	567	1530
	743	1540
	878	1550
	971	1600
	1012	1610
29/2	907	1620
	720	1630
	413	1640
	48	1650
29A1	52	1830
	312	1840
	794	1850
	1321	1900
	1401	1910
	1664	1920
29A2	1583	1930
	1132	1940
	525	1950
	35	2000
29B1	104	0020
	313	0030
	497	0040
	635	0050
	792	0100
	872	0110
	991	0120
	1129	0130
	1262	0140
	1352	0150
	1439	0200
	1554	0210
29B2	1485	0220
	1324	0230
	1094	0240
	872	0250
	656	0300
	405	0310
	0	0320
30/1	29	1610
	138	1620
	347	1630
	526	1640
	743	1650
	885	1700
	1057	1710
	1172	1720
	1352	1730
	1521	1740
	1689	1750
	1808	1800
	2165	1810

Profile	D(m)	GMT
30/2	2247	1820
	2150	1830
	2034	1840
	1934	1850
	1777	1900
	1587	1910
	130[illegible]	1920
	93[illegible]	1930
	60[illegible]	1940
30/3	57[illegible]	1950
	966	2000
	110[illegible]	2010
	124[illegible]	2020
	140[illegible]	2030
	160[illegible]	2040
30/4	165[illegible]	2100
	144[illegible]	2110
	125[illegible]	2120
	106[illegible]	2130
	79[illegible]	2140
	60[illegible]	2150
	32[illegible]	2200
	[illegible]	2210
31/1	7[illegible]	1440
	23[illegible]	1450
	40[illegible]	1500
	78[illegible]	1510
	72[illegible]	1520
	84[illegible]	1530
	103[illegible]	1540
	117[illegible]	1550
	130[illegible]	1600
	140[illegible]	1610
	163[illegible]	1620
	175[illegible]	1630
31/2	174[illegible]	1650
	161[illegible]	1700
	144[illegible]	1710
	134[illegible]	1720
	122[illegible]	1730
	105[illegible]	1740
	97[illegible]	1750
	84[illegible]	1800
	74[illegible]	1810
	63[illegible]	1820
	50[illegible]	1830
31/3	53[illegible]	1840
	70[illegible]	1850
	85[illegible]	1900
	109[illegible]	1910
	125[illegible]	1920
	139[illegible]	1930
	154[illegible]	1940
	168[illegible]	1950

Profile	D(m)	GMT
31/4	1717	2010
	1532	2020
	1237	2030
	1091	2040
	951	2050
	754	2100
	557	2110
	443	2120
	209	2130
	0	2140
31/5	122	2150
	1151	2200
31/6	1318	2210
	820	2220
	132	2230
32/1	26	0840
	248	0850
	443	0900
	686	0910
	898	0920
	1090	0930
	1264	0940
	1462	0950
	1625	1000
	1804	1010
32/2	1790	1020
	1682	1030
	1588	1040
	1369	1050
	1187	1100
	1029	1110
	882	1120
	627	1130
32/3	536	1140
	740	1150
	833	1200
	991	1210
	1141	1220
	1339	1230
	1567	1240
	1770	1250
32/4	1659	1310
	1617	1320
	1501	1330
	1371	1340
	1260	1350
	1117	1400
	948	1410
	877	1420
	849	1430
	566	1440
	162	1450

Profile	D(m)	GMT
33/1	308	2240
	708	2250
	918	2300
	1054	2310
	1203	2320
	1326	2330
	1445	2340
	1644	2350
	1808	2400
33/2	1773	0010
	1647	0020
	1495	0030
	1355	0040
	1173	0050
	949	0100
	671	0110
	382	0120
	83	0130
34/1	2	1010
	153	1020
	321	1030
	499	1040
	656	1050
	875	1100
	986	1110
	1160	1120
	1294	1130
	1487	1140
	1661	1150
	1724	1200
	1827	1210
34/2	1802	1220
	1723	1230
	1643	1240
	1521	1250
	1388	1300
	1294	1310
	1168	1320
	1053	1330
	960	1340
	789	1350
	585	1400
	400	1410
34/3	487	1420
	686	1430
	873	1440
	1116	1450
	1331	1500
	1550	1510
	1698	1520
	1830	1530

Profile	D(m)	GMT
34/4	1715	1540
	1389	1550
	1074	1600
	876	1610
	644	1620
	303	1630
	54	1640
35/1	1	0820
	41	0830
	225	0840
	406	0850
	590	0900
	783	0910
	957	0920
35/2	839	0930
	701	0940
	554	0950
	413	1000
	268	1010
	118	1020
36/1	36	1140
	366	1150
	540	1200
	769	1210
	995	1220
	1202	1230
	1400	1240
36/2	314	0850
	549	0900
	756	0910
	940	0920
	1164	0930
36/3	1085	0950
	781	1000
	567	1010
37/1	6	1140
	231	1150
	466	1200
	658	1210
37/2	204	1310
	643	1320
	907	1330
37/3	901	1340
	716	1350
	518	1400
	300	1410
38/1	12	1840
	356	1850
	564	1900
	779	1910
	965	1920
	1168	1930
	1319	1940

Profile	D(m)	GMT
38/2	1270	1950
	1084	2000
	903	2010
	711	2020
	516	2030
	213	2040
39/1	0	0620
	254	0630
	786	0640
39/2	917	0650
	322	0700
	17	0710
39/3	108	1010
	474	1020
	849	1030
	1203	1040
	1525	1050
	1781	1100
39/4	1806	1110
	1683	1120
	1094	1130
	664	1140
	227	1150

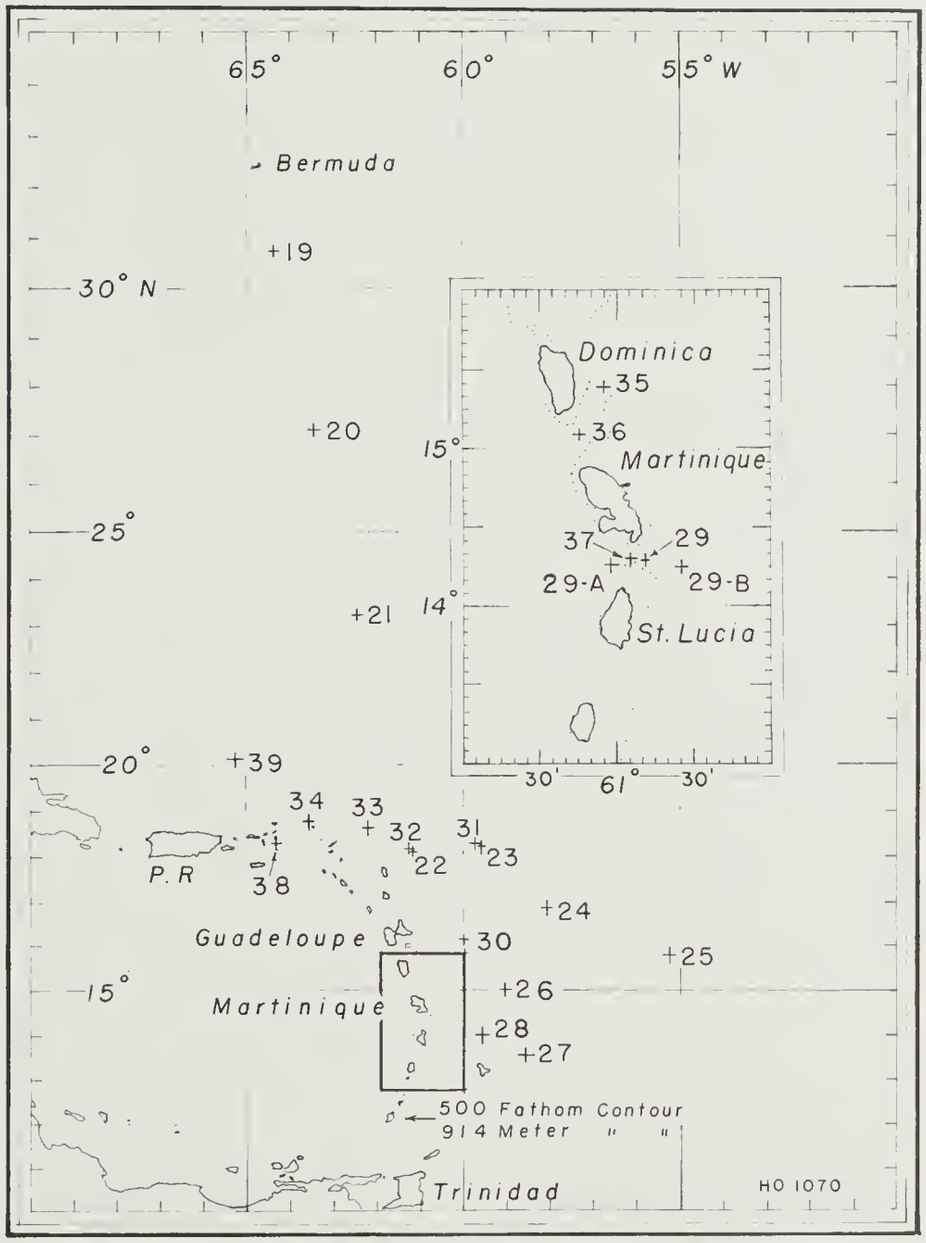


Fig. 1 Chart of Stations

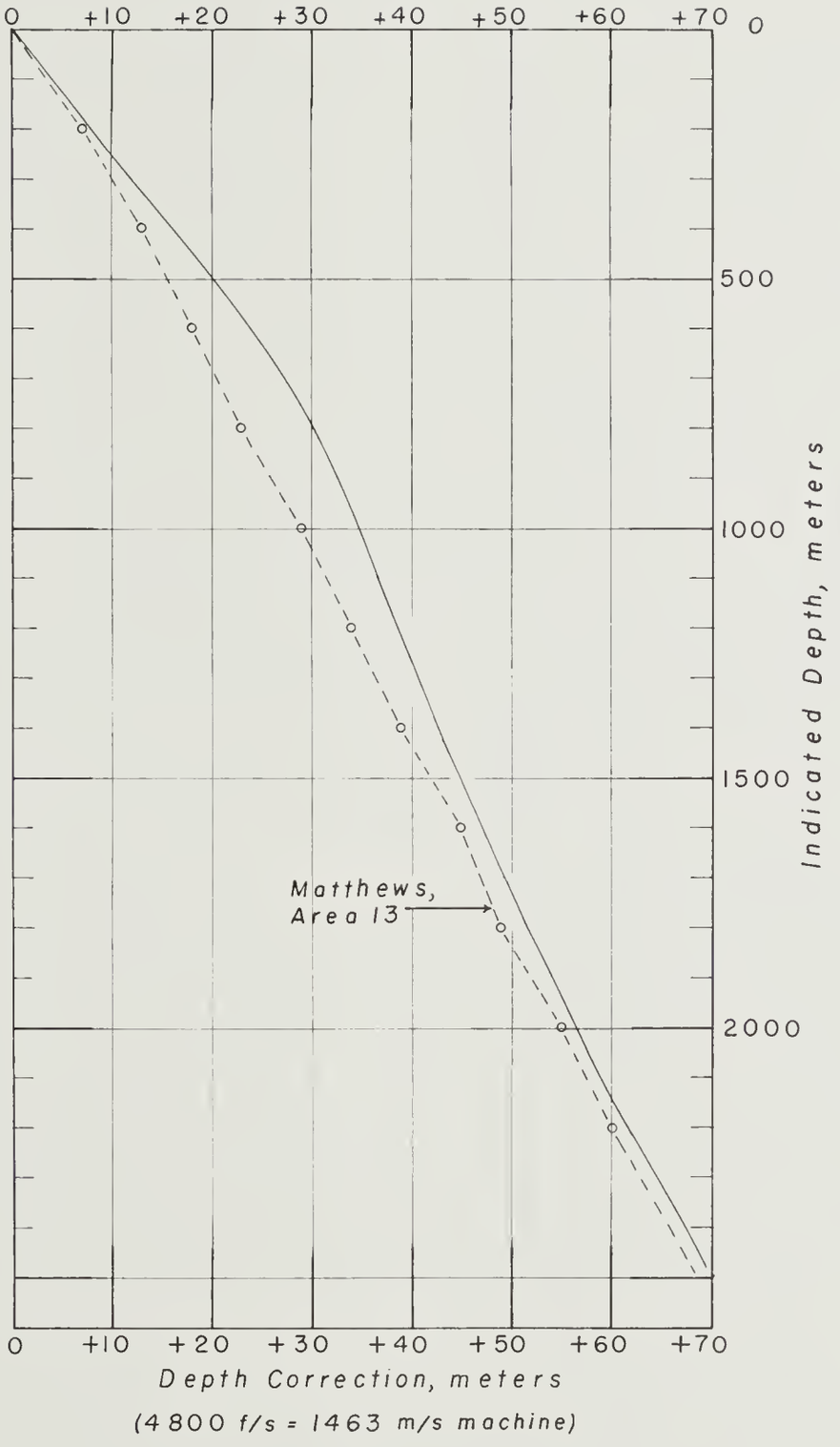
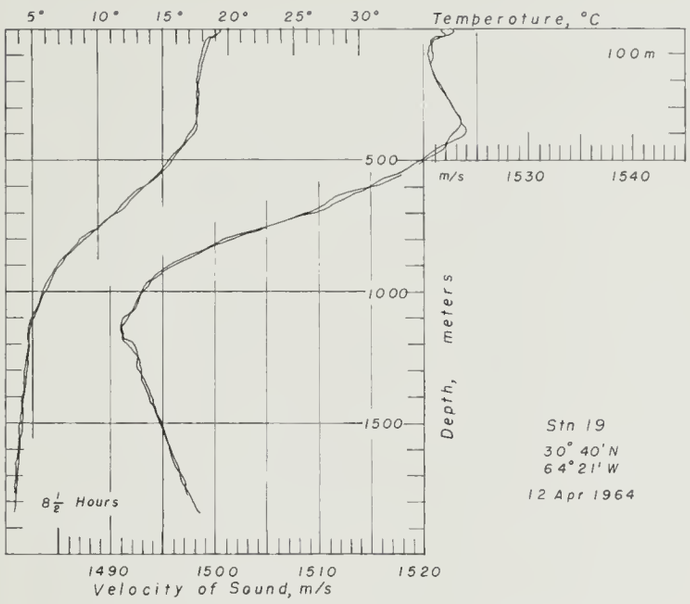
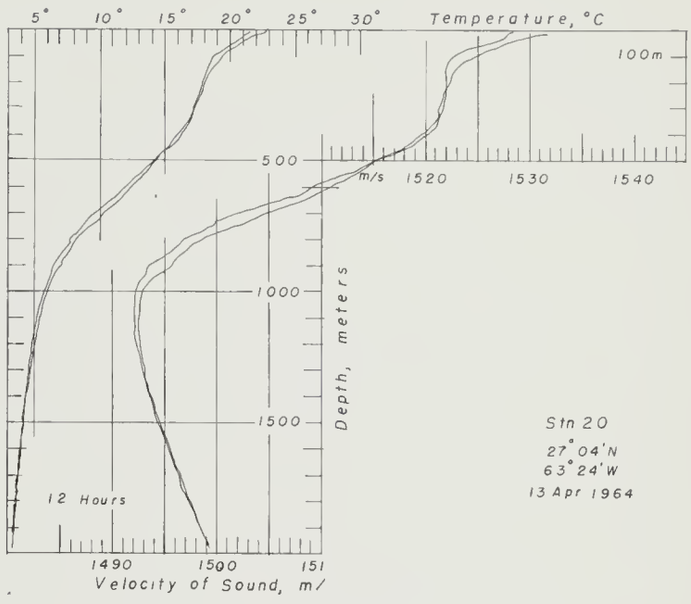
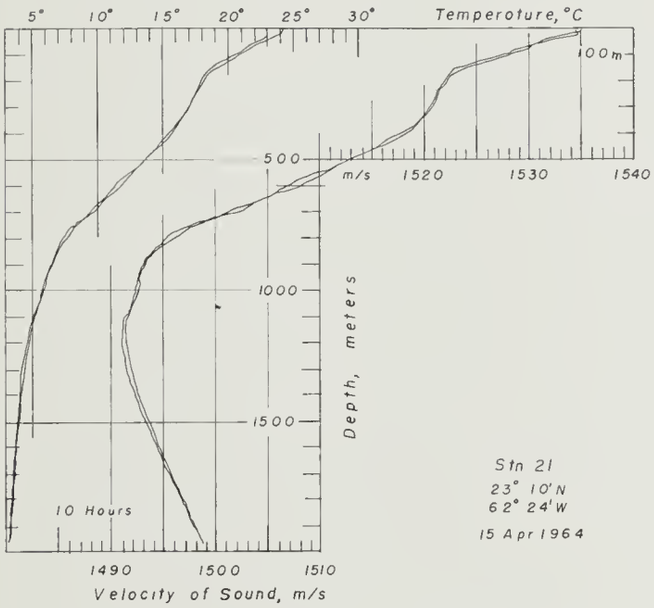
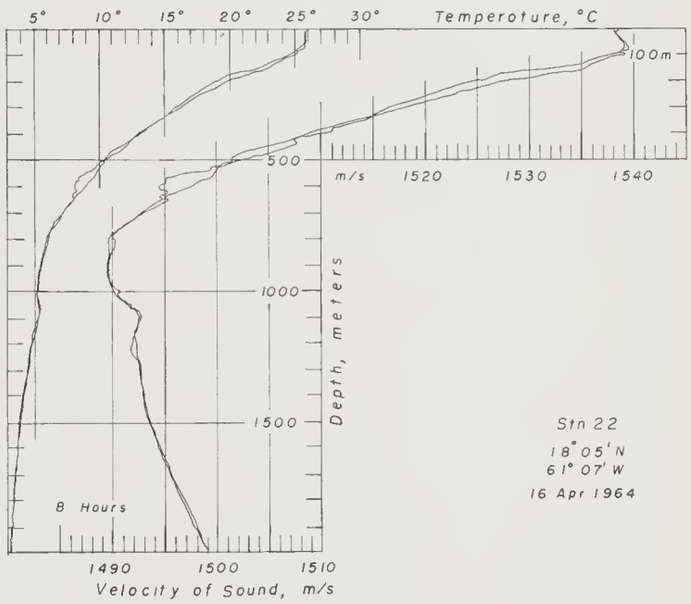


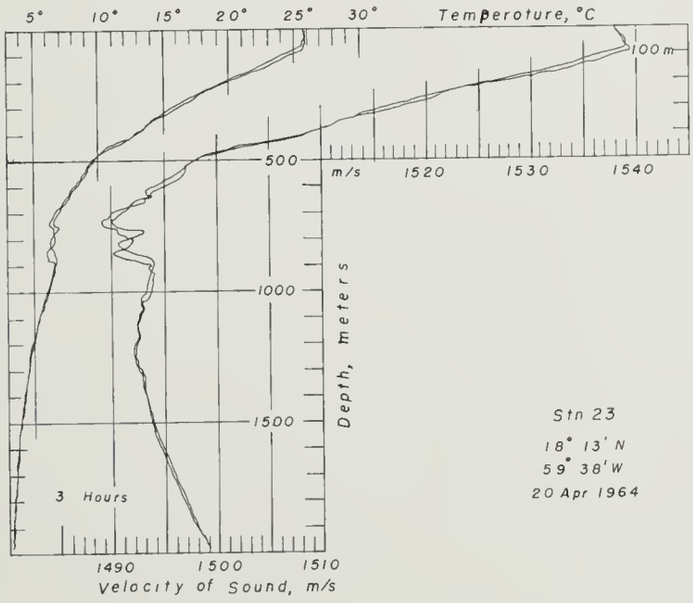
Fig.2 Conversion of indicated to true depth











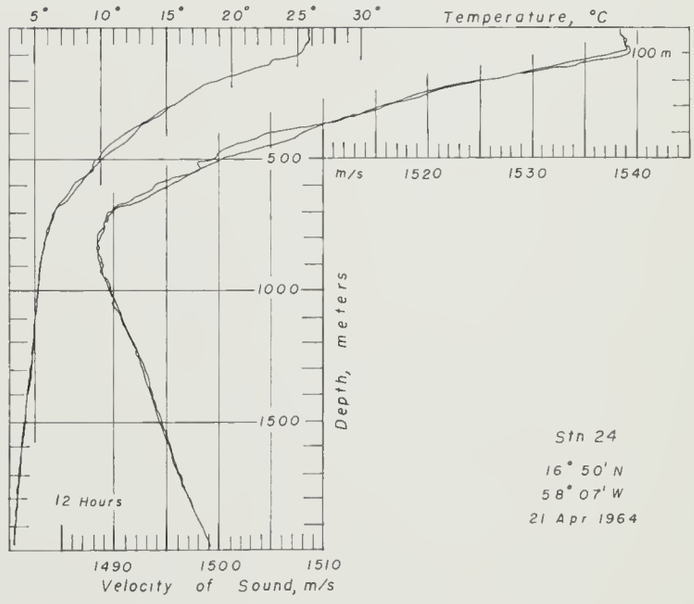
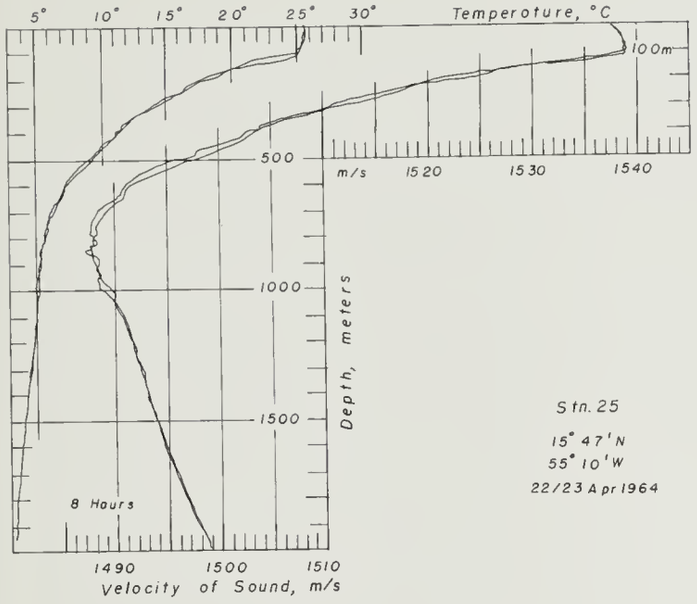
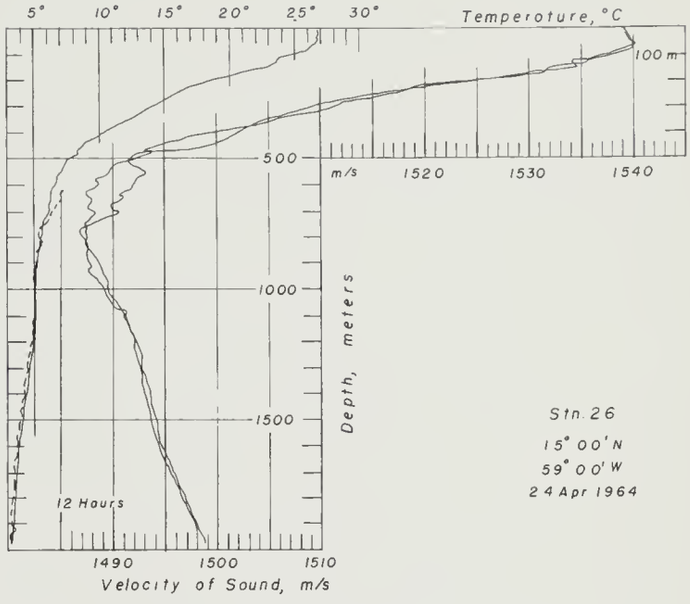


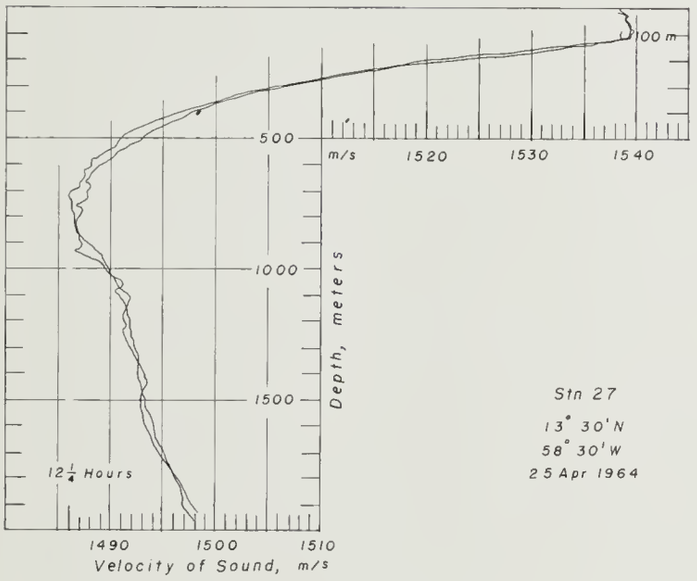
Fig. 3 First and last profiles, Stations 19-24



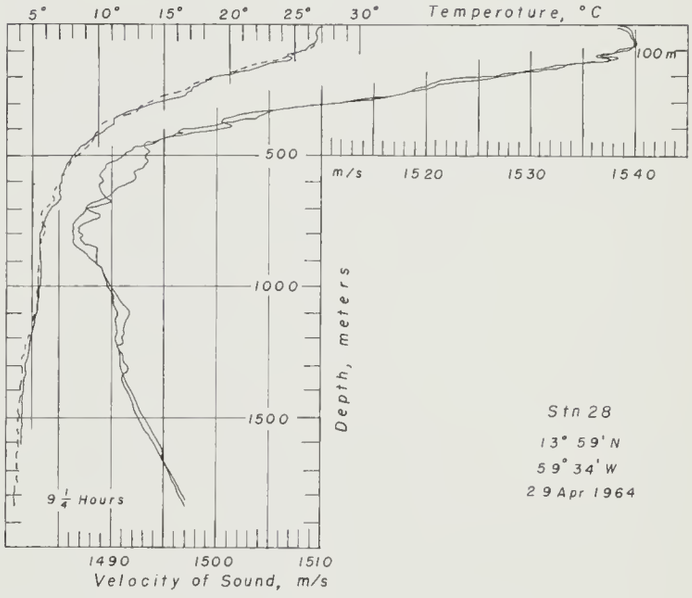
Stn. 25
15° 47' N
55° 10' W
22/23 Apr 1964



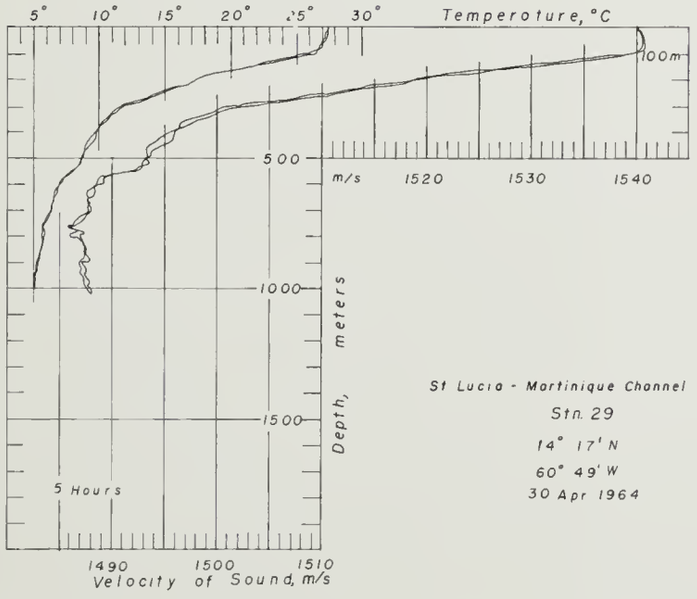
Stn. 26
15° 00' N
59° 00' W
24 Apr 1964



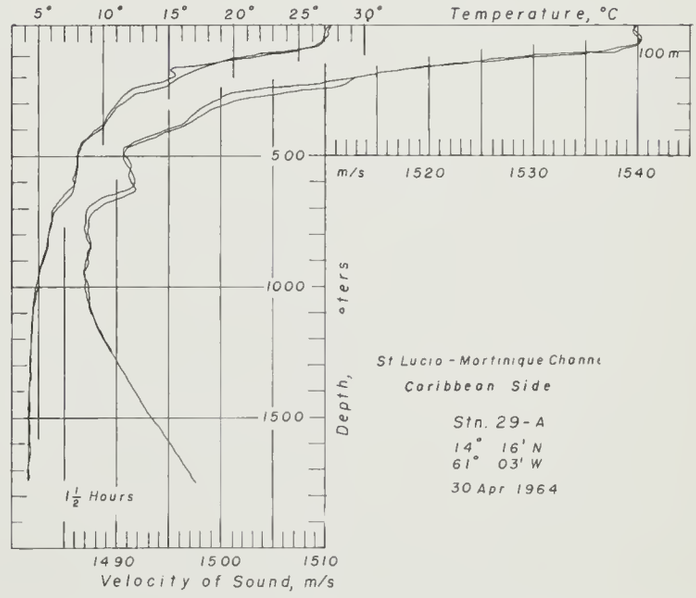
Stn 27
13° 30' N
58° 30' W
25 Apr 1964



Stn 28
13° 59' N
59° 34' W
29 Apr 1964

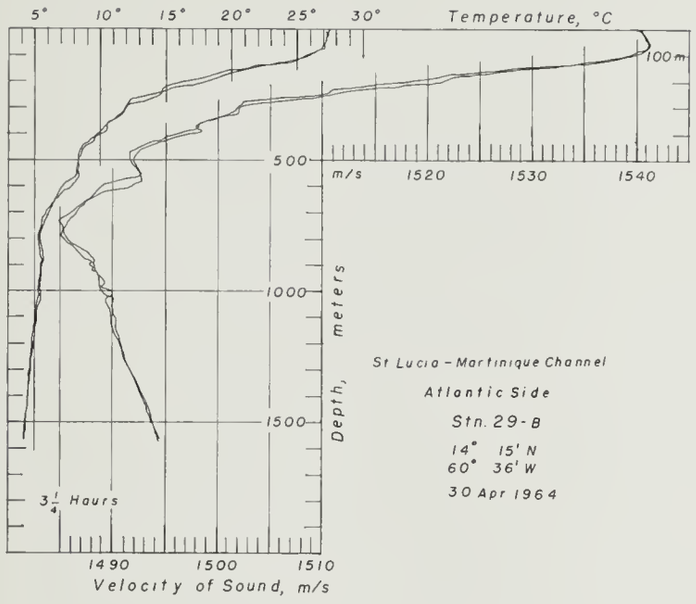


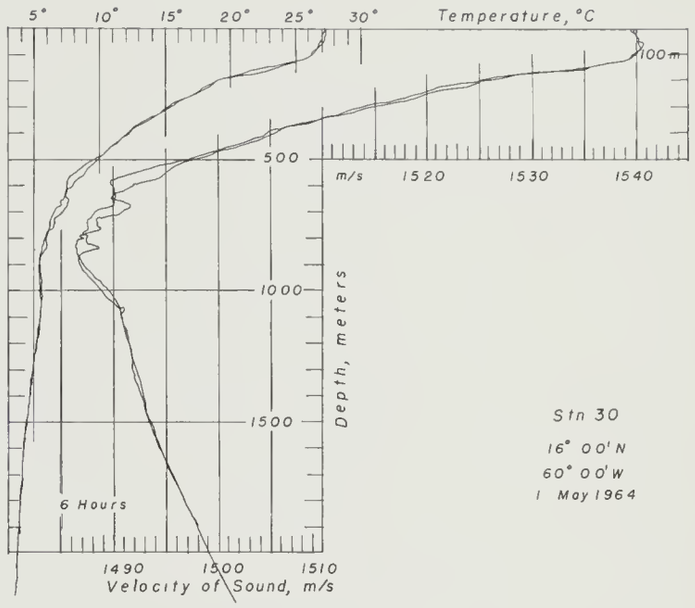
St Lucia - Martinique Channel
Stn. 29
14° 17' N
60° 49' W
30 Apr 1964

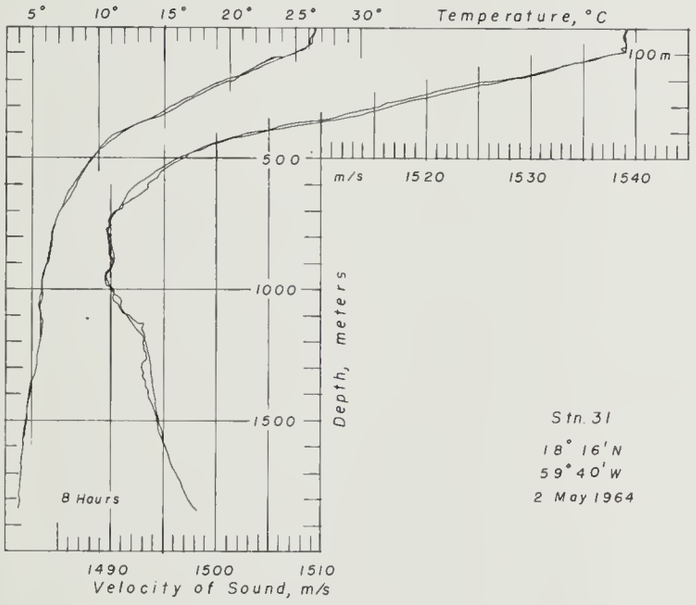


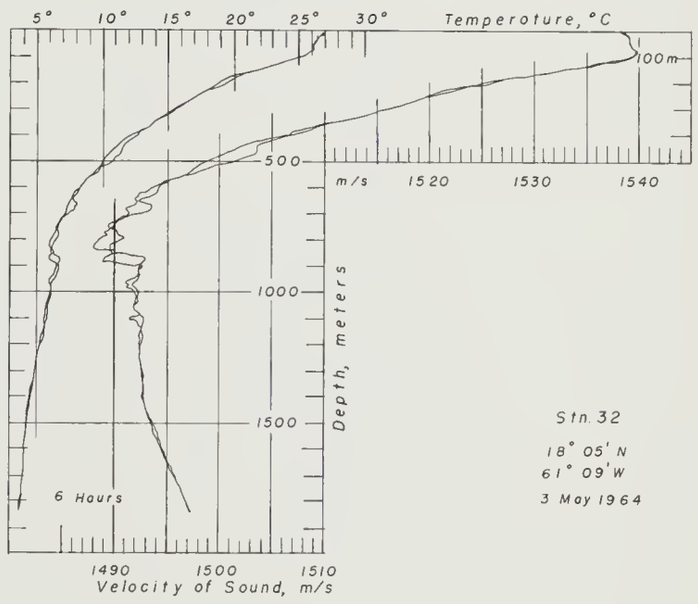
St Lucia - Martinique Channe
Caribbean Side
Stn. 29-A
14° 16' N
61° 03' W
30 Apr 1964

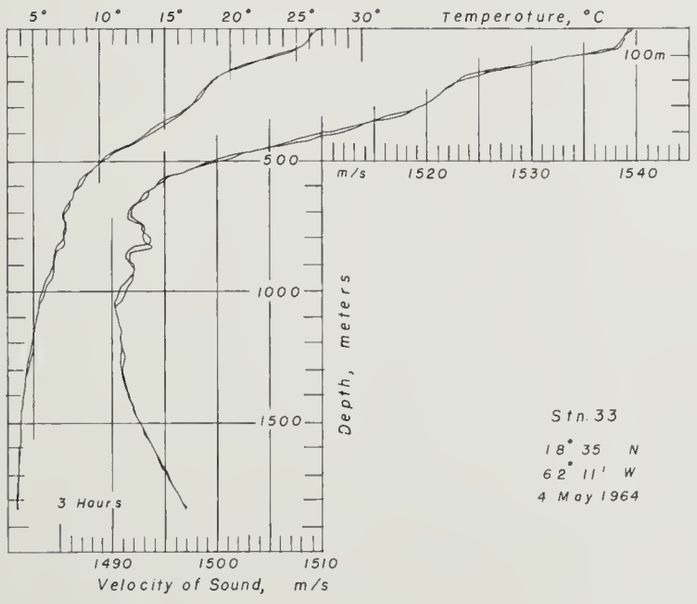
Fig. 4 First and last profiles, Stations 25-29A











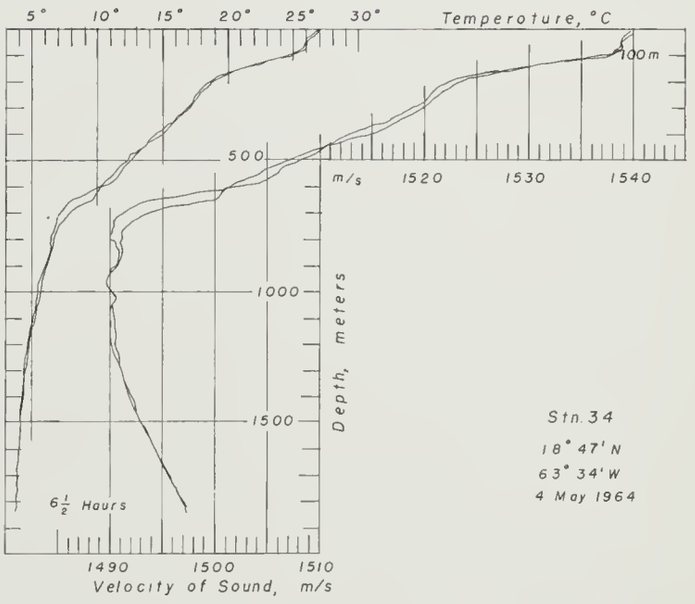
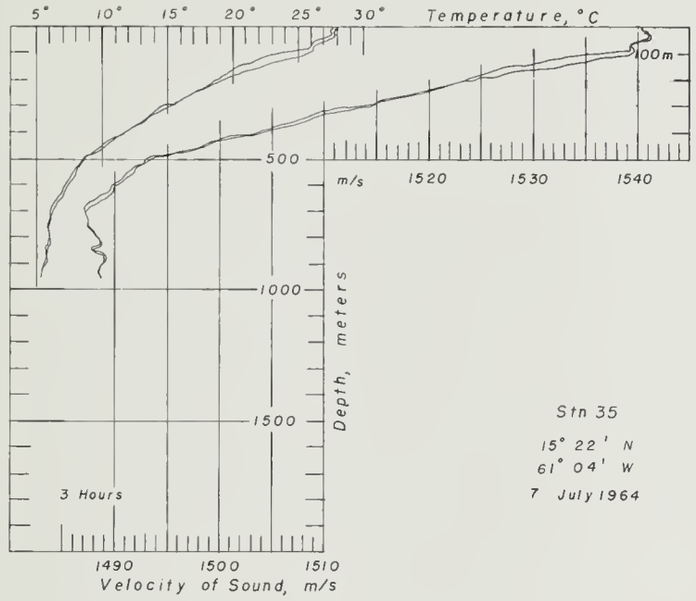
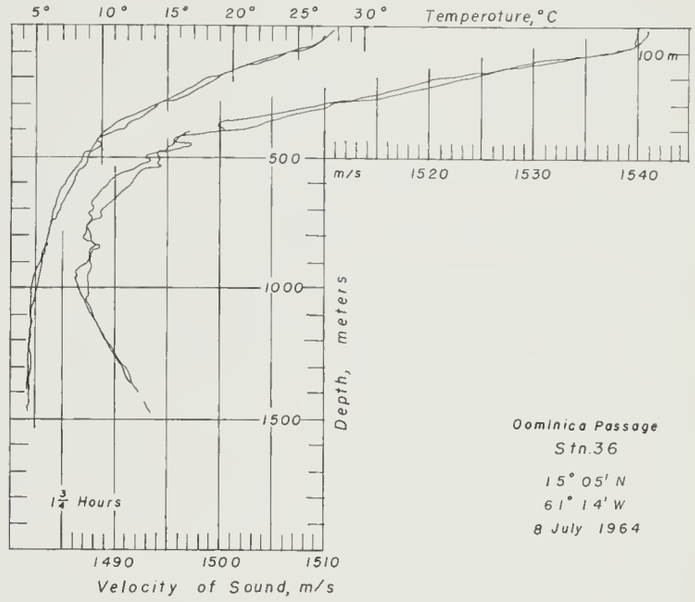


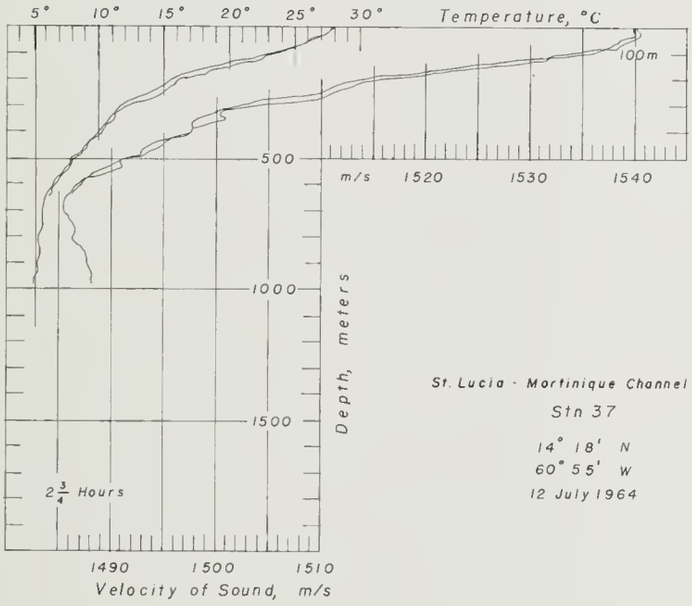
Fig. 5 First and last profiles, Stations 29B-34



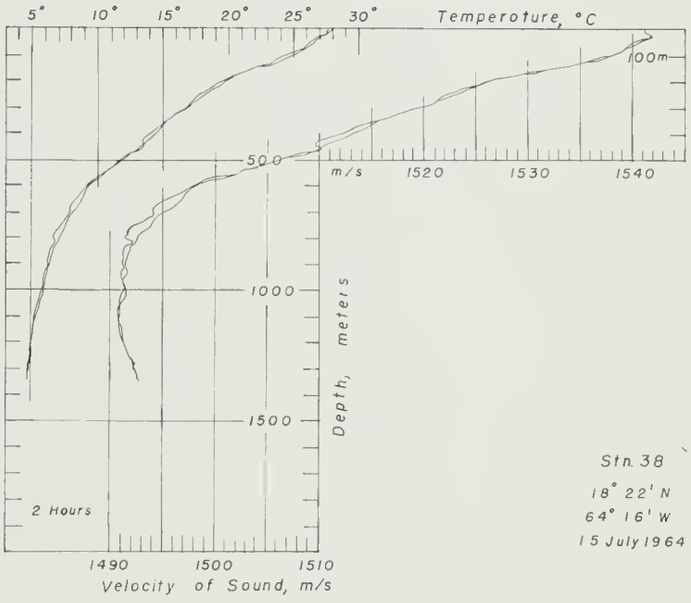
Stn 35
15° 22' N
61° 04' W
7 July 1964



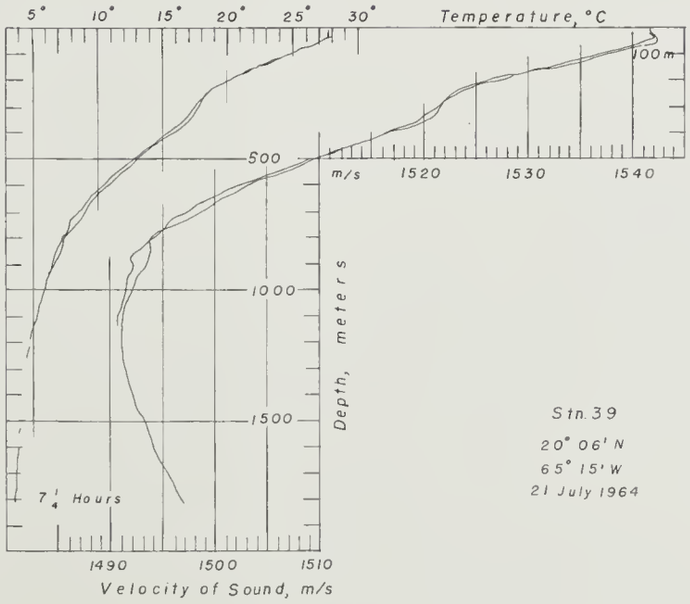
Dominica Passage
Stn.36
15° 05' N
61° 14' W
8 July 1964



St. Lucia - Martinique Channel
Stn 37
14° 18' N
60° 55' W
12 July 1964



Stn. 38
18° 22' N
64° 16' W
15 July 1964



Stn. 39
20° 06' N
65° 15' W
21 July 1964

Fig.6 First and last profiles, Stations 35-39

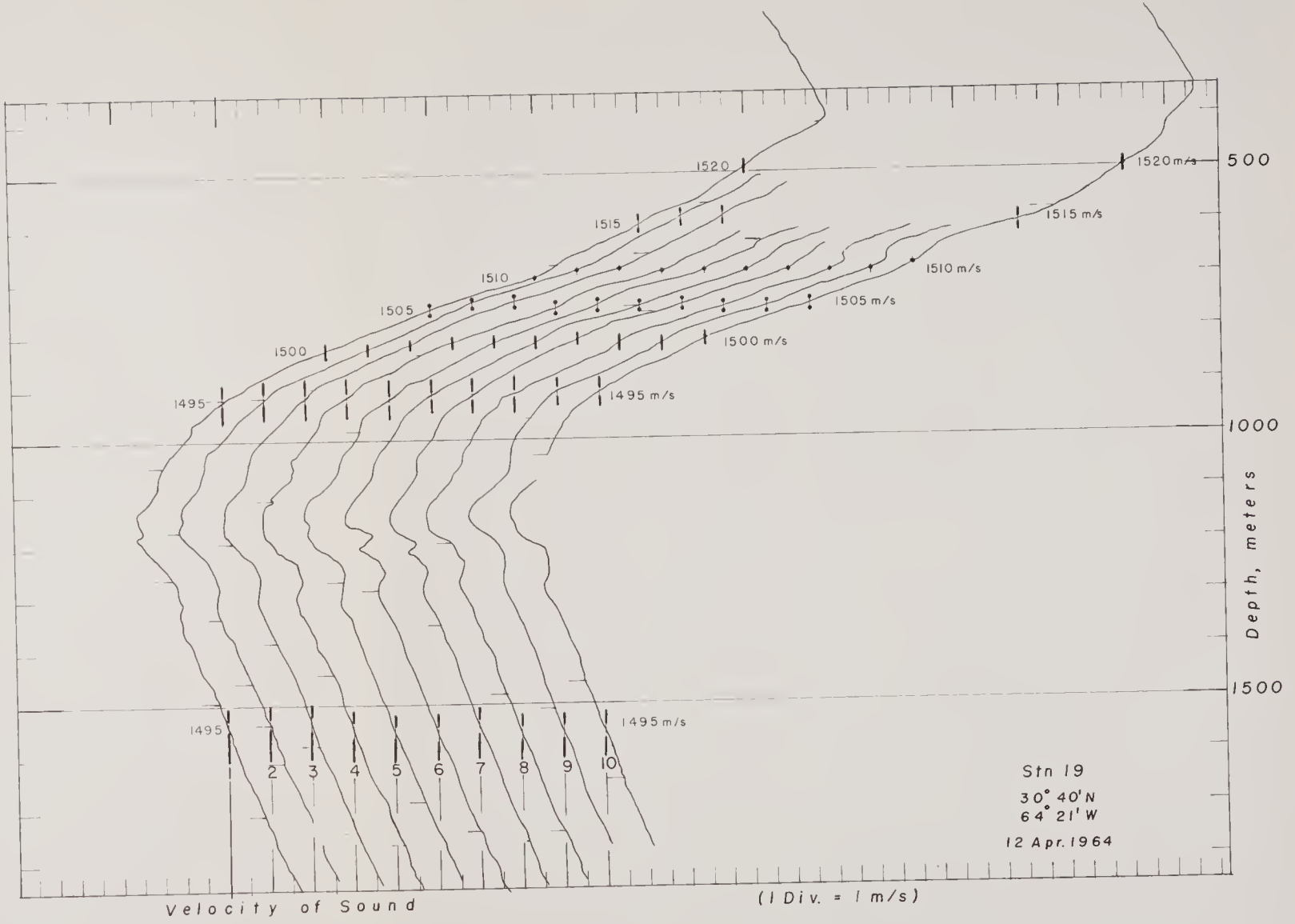


Fig. 7 Profile family, Station 19

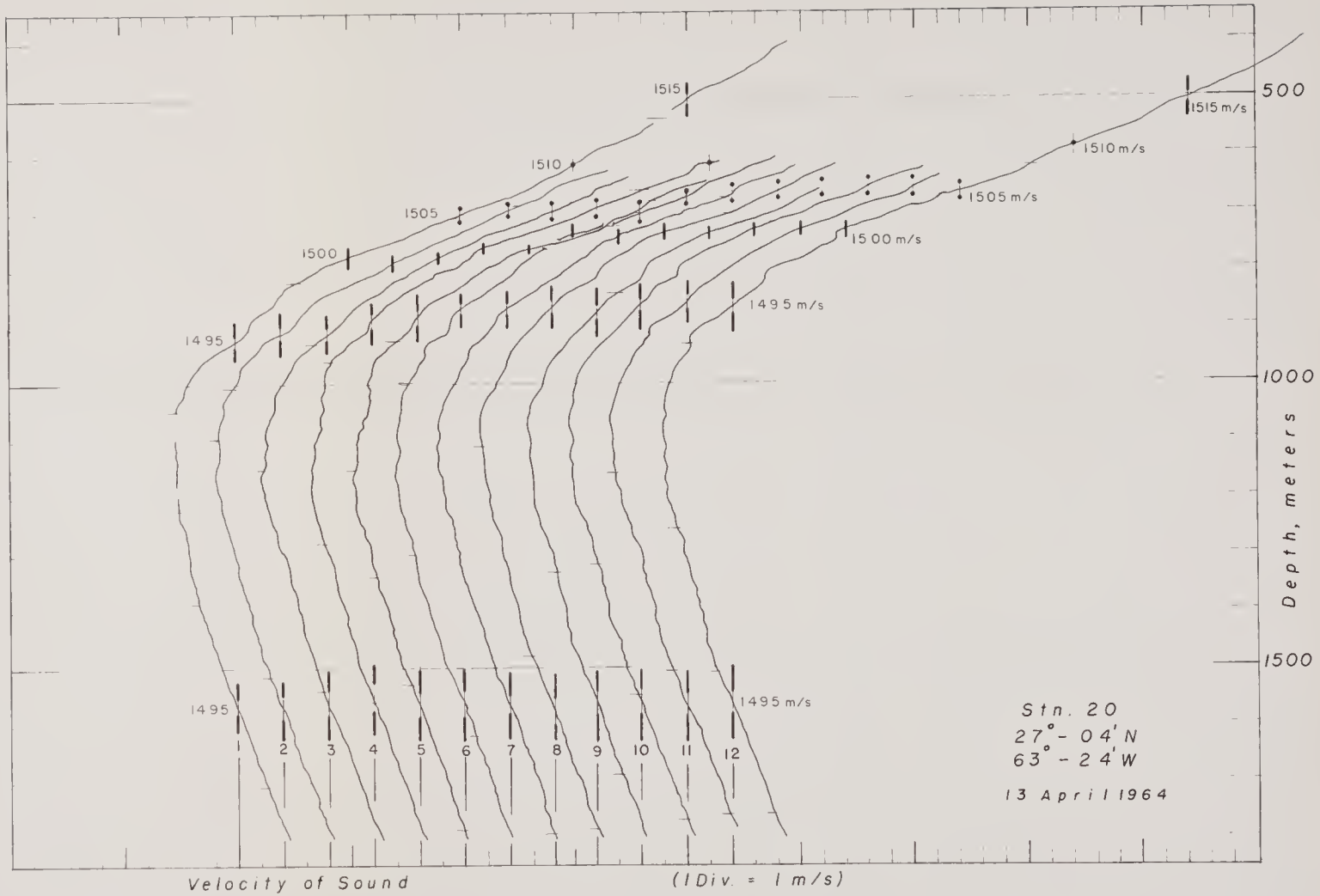


Fig. 8 Profile family, Station 20

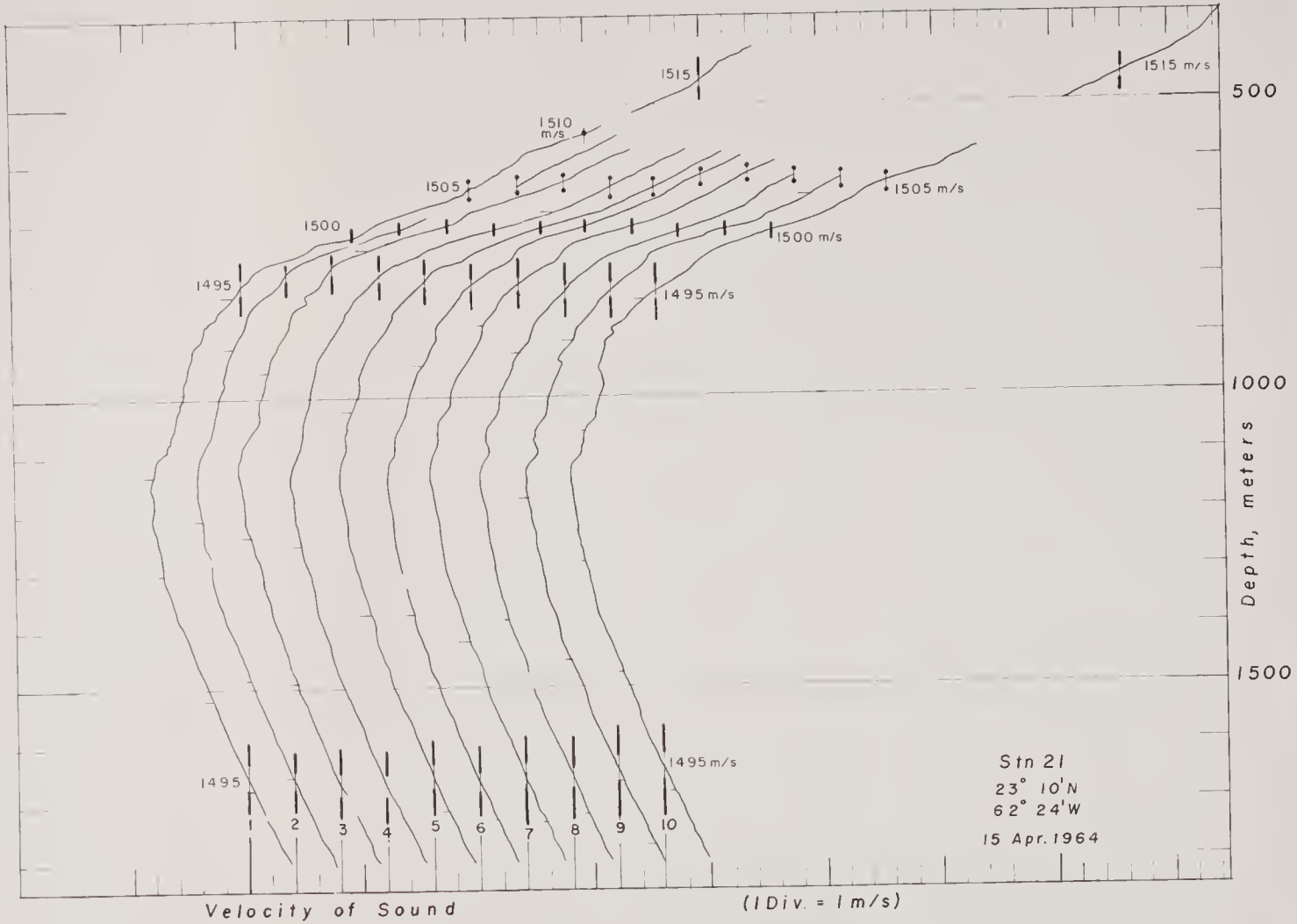


Fig. 9 Profile family, Station 21

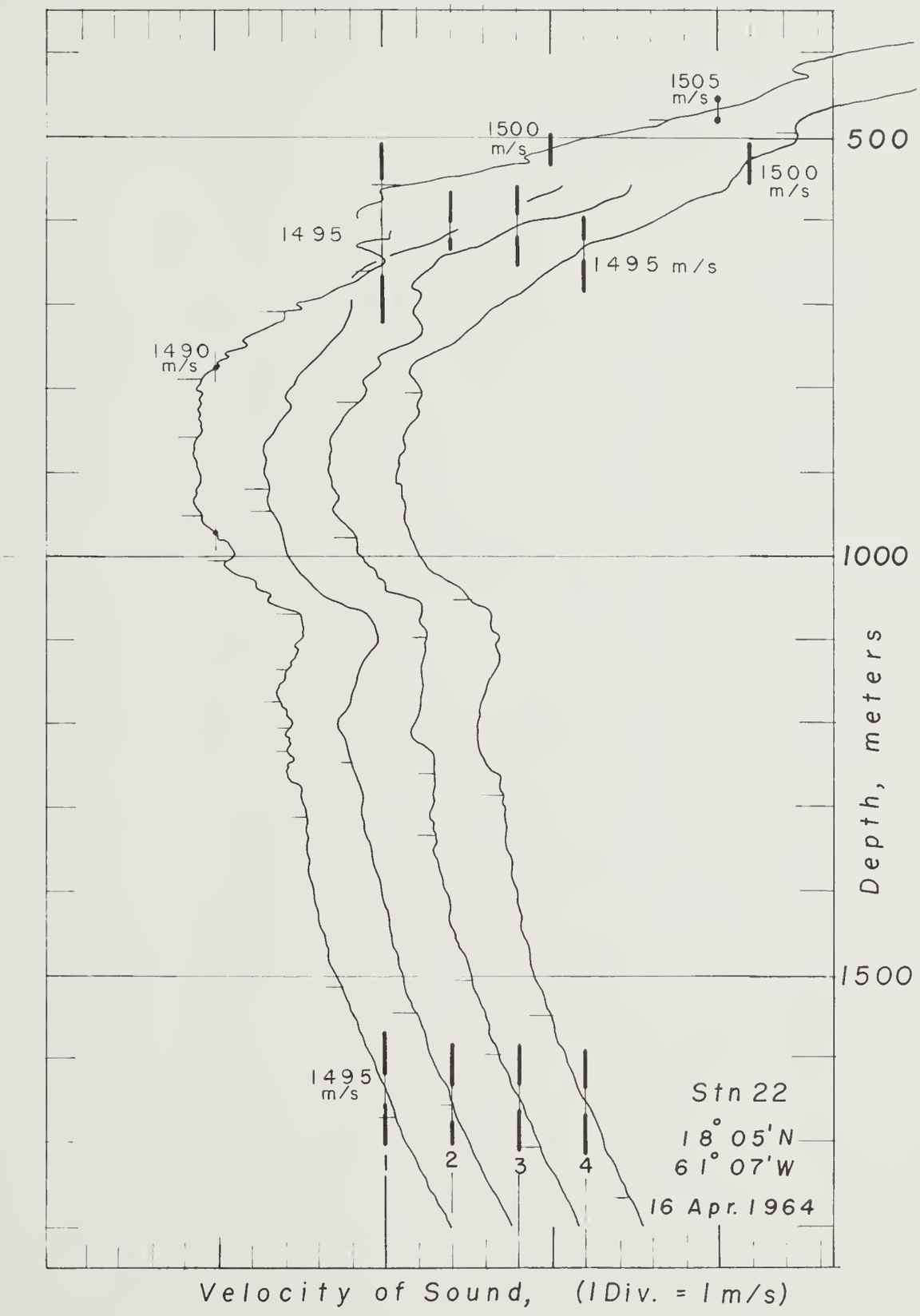


Fig. 10 Profile family, Station 22

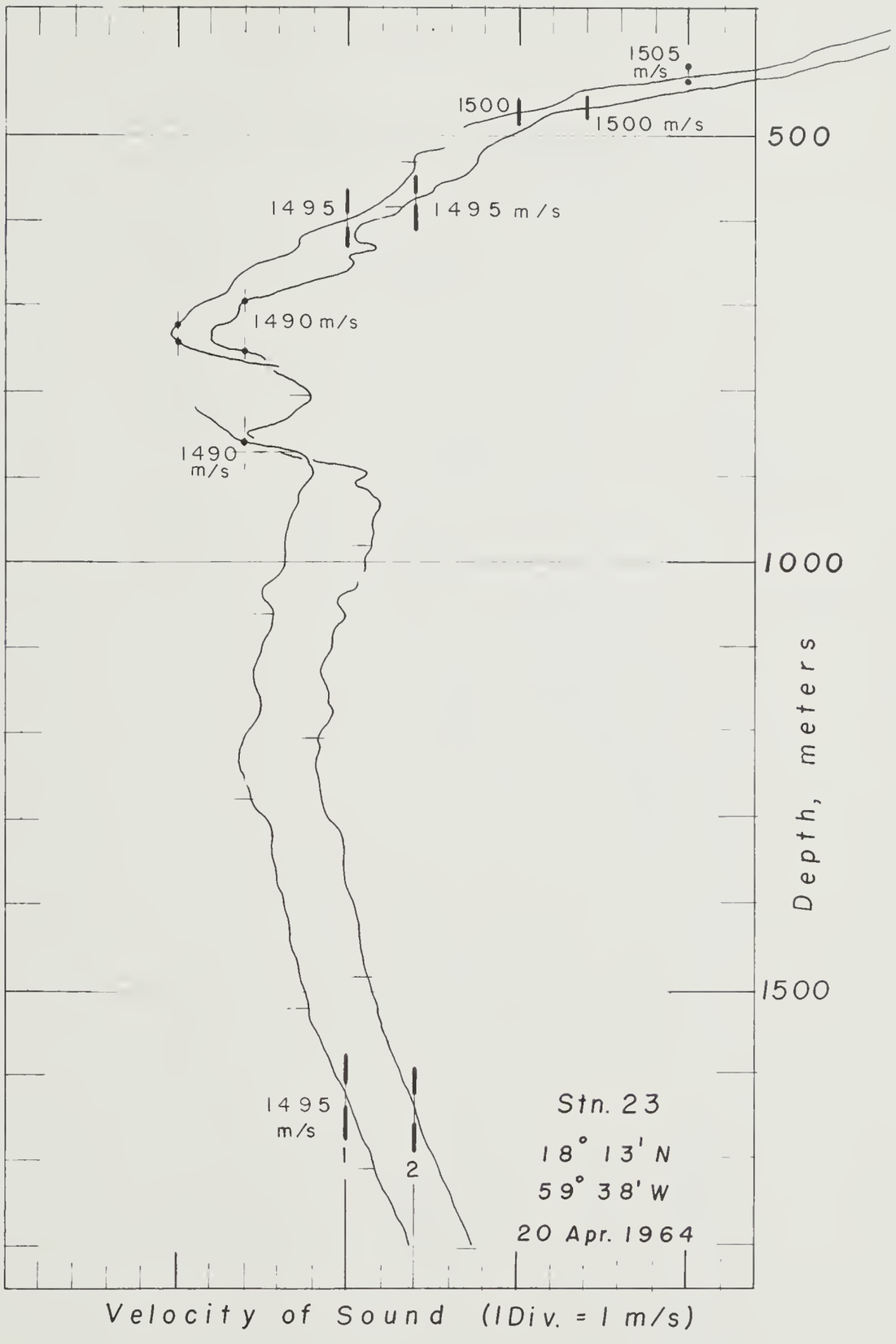


Fig. 11 Profile family, Station 23

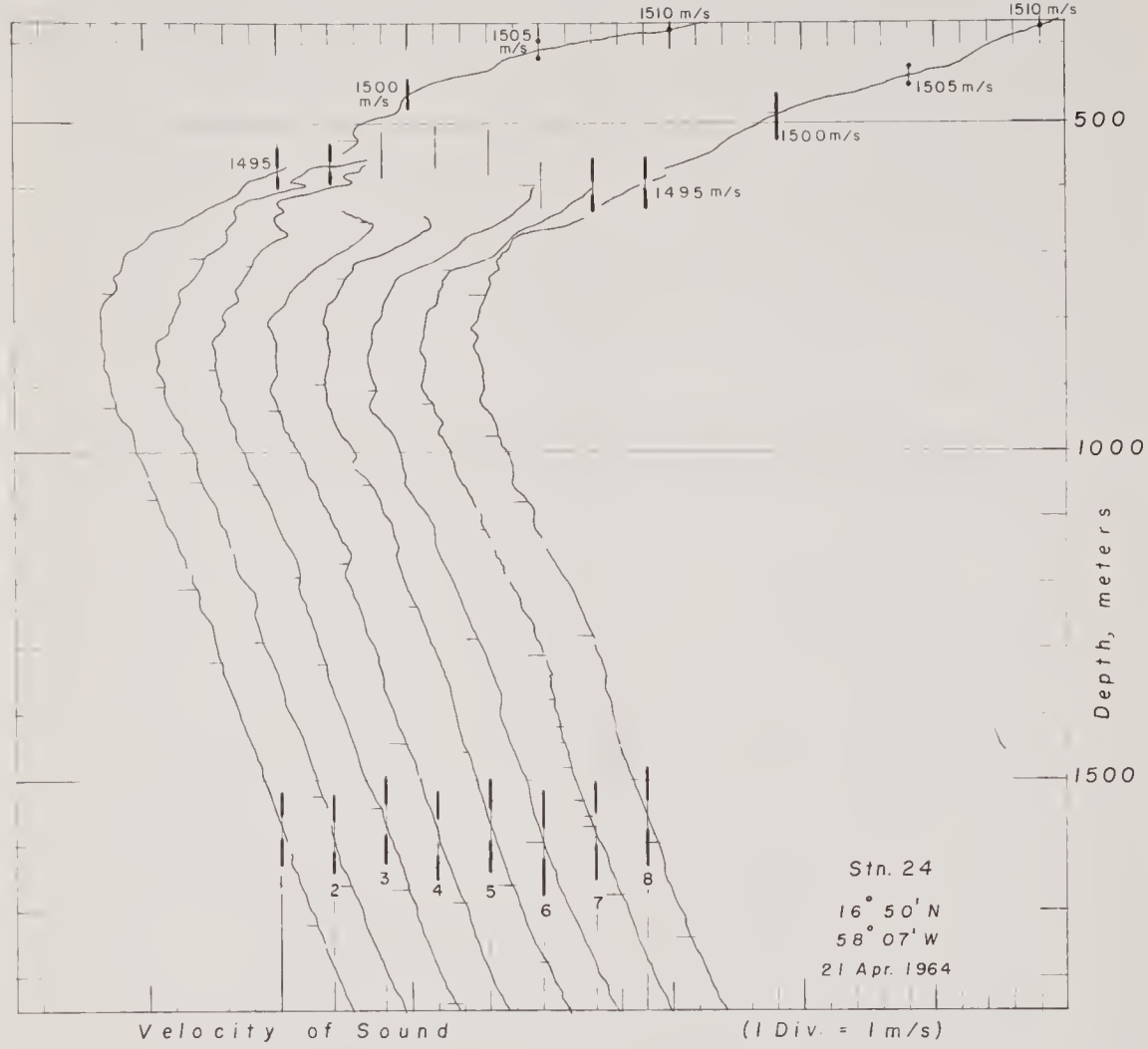


Fig.12 Profile family, Station 24

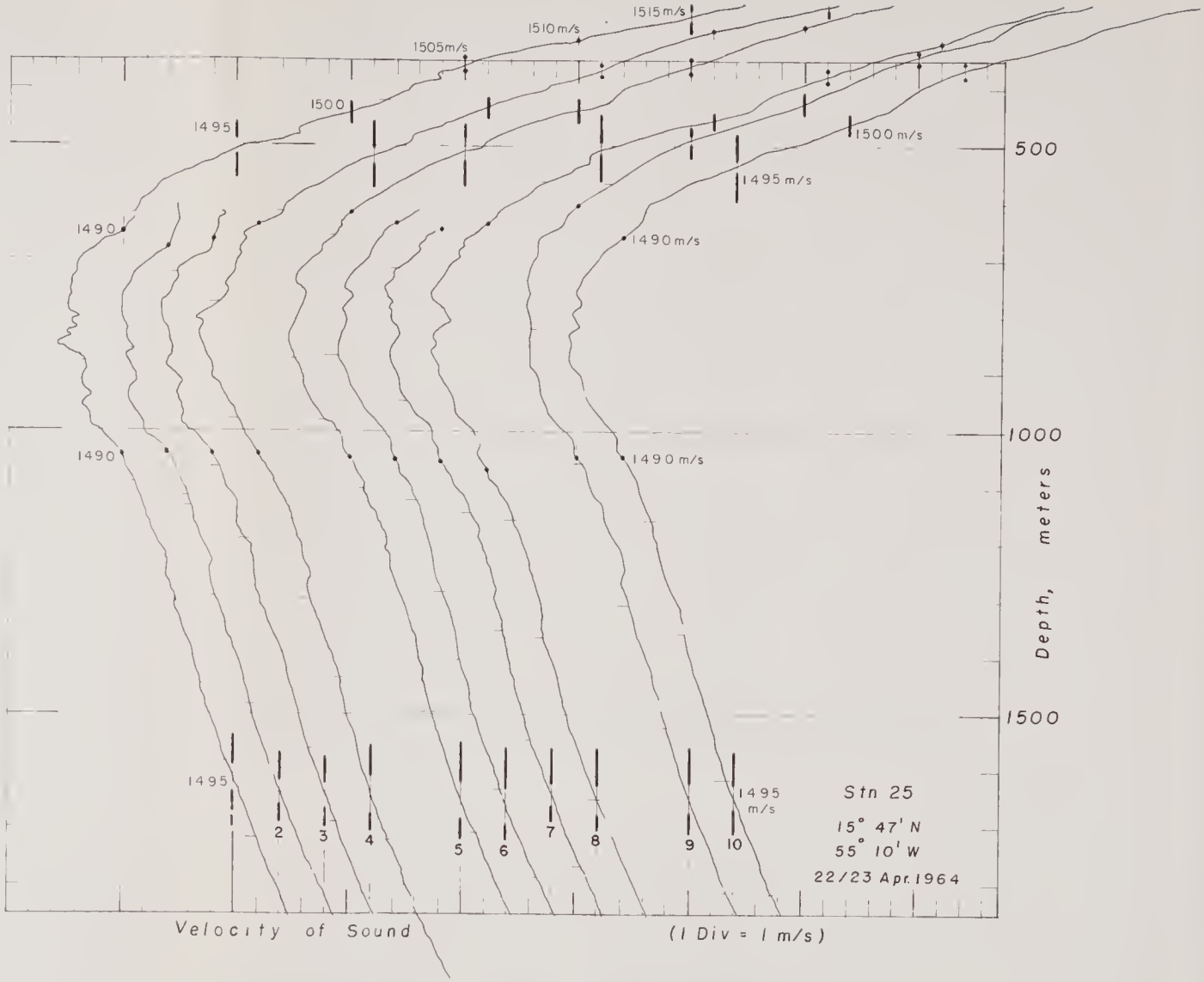


Fig. 13 Profile family, Station 25

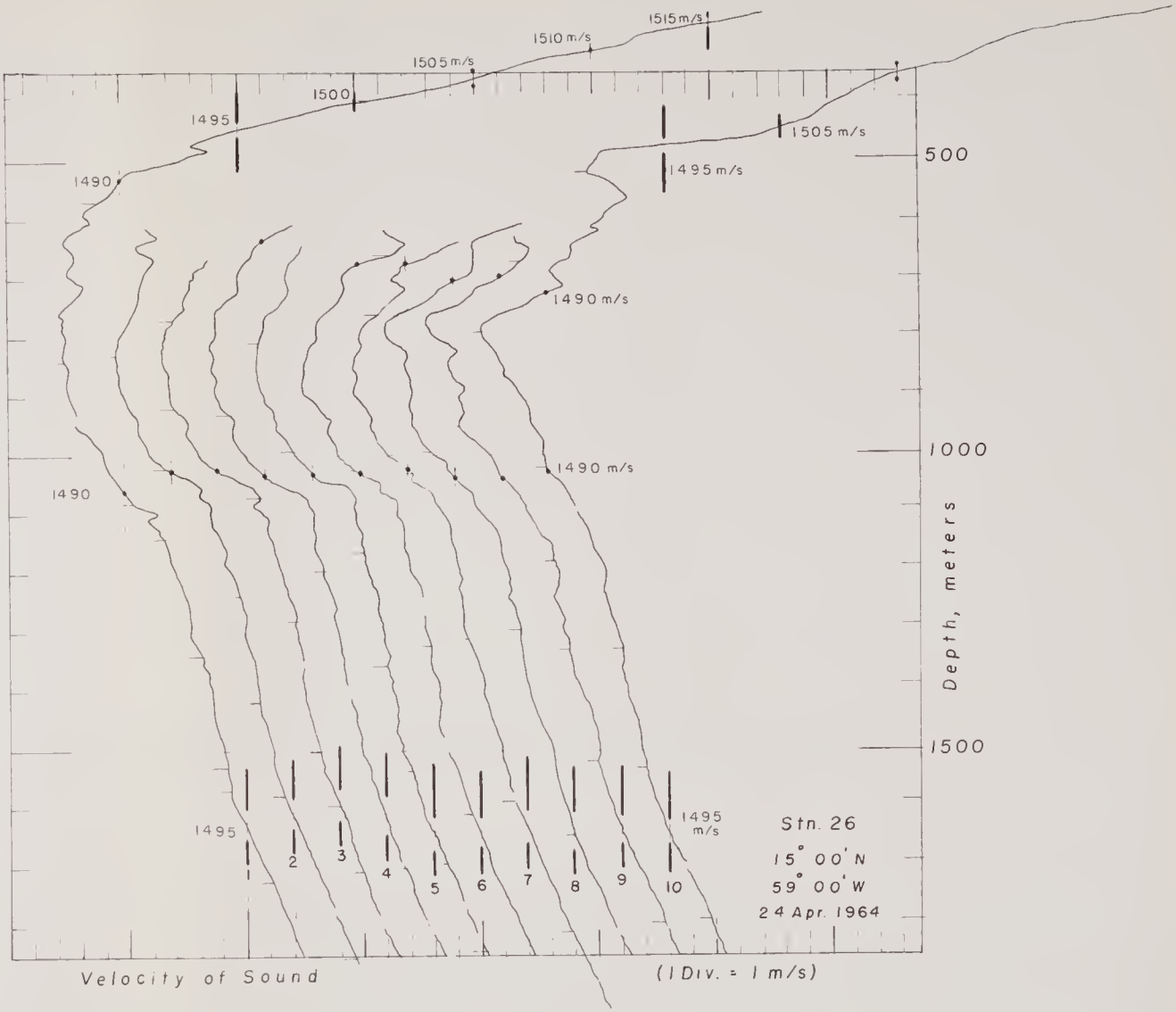


Fig. 14 Profile family, Station 26

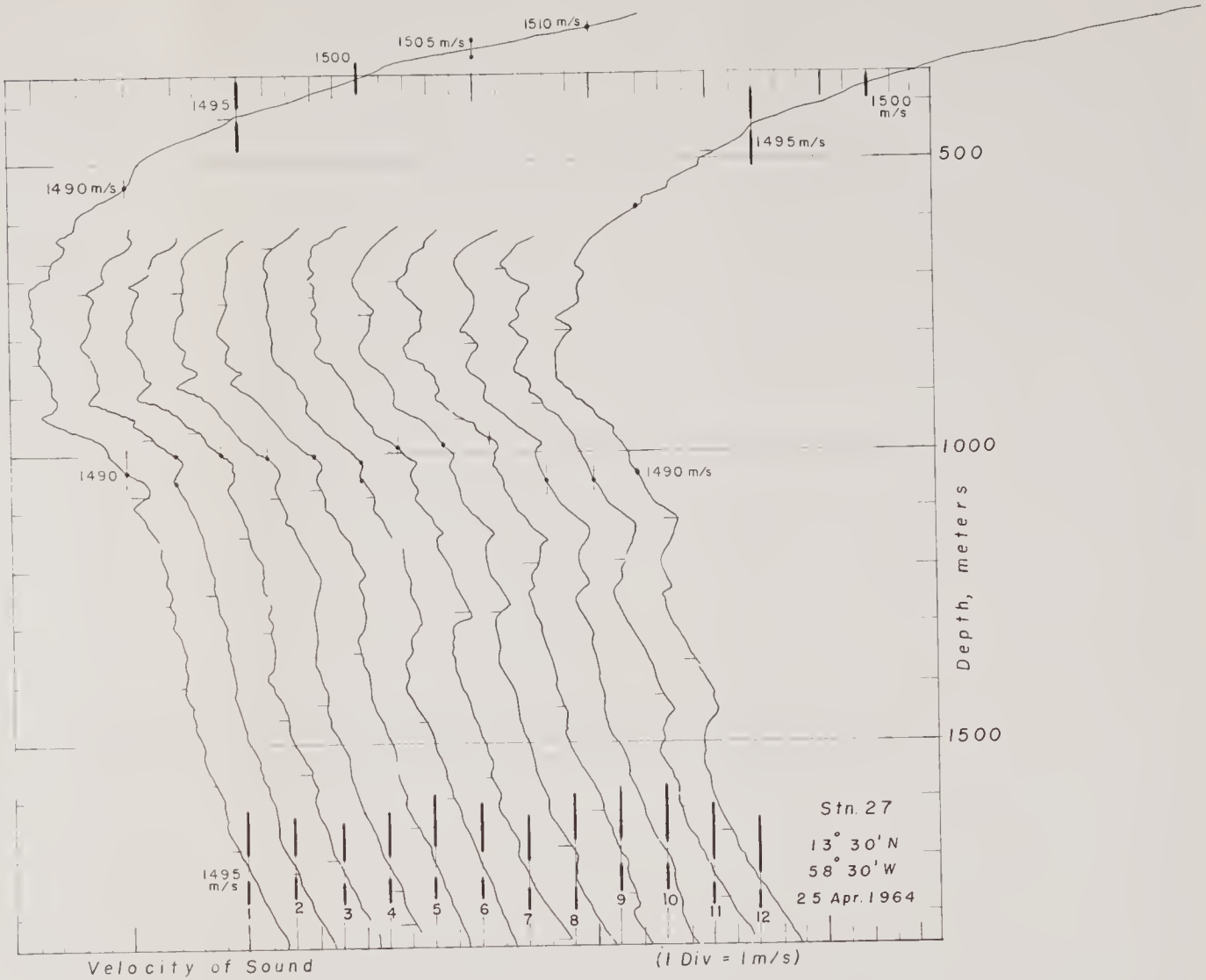


Fig. 15 Profile family, Station 27

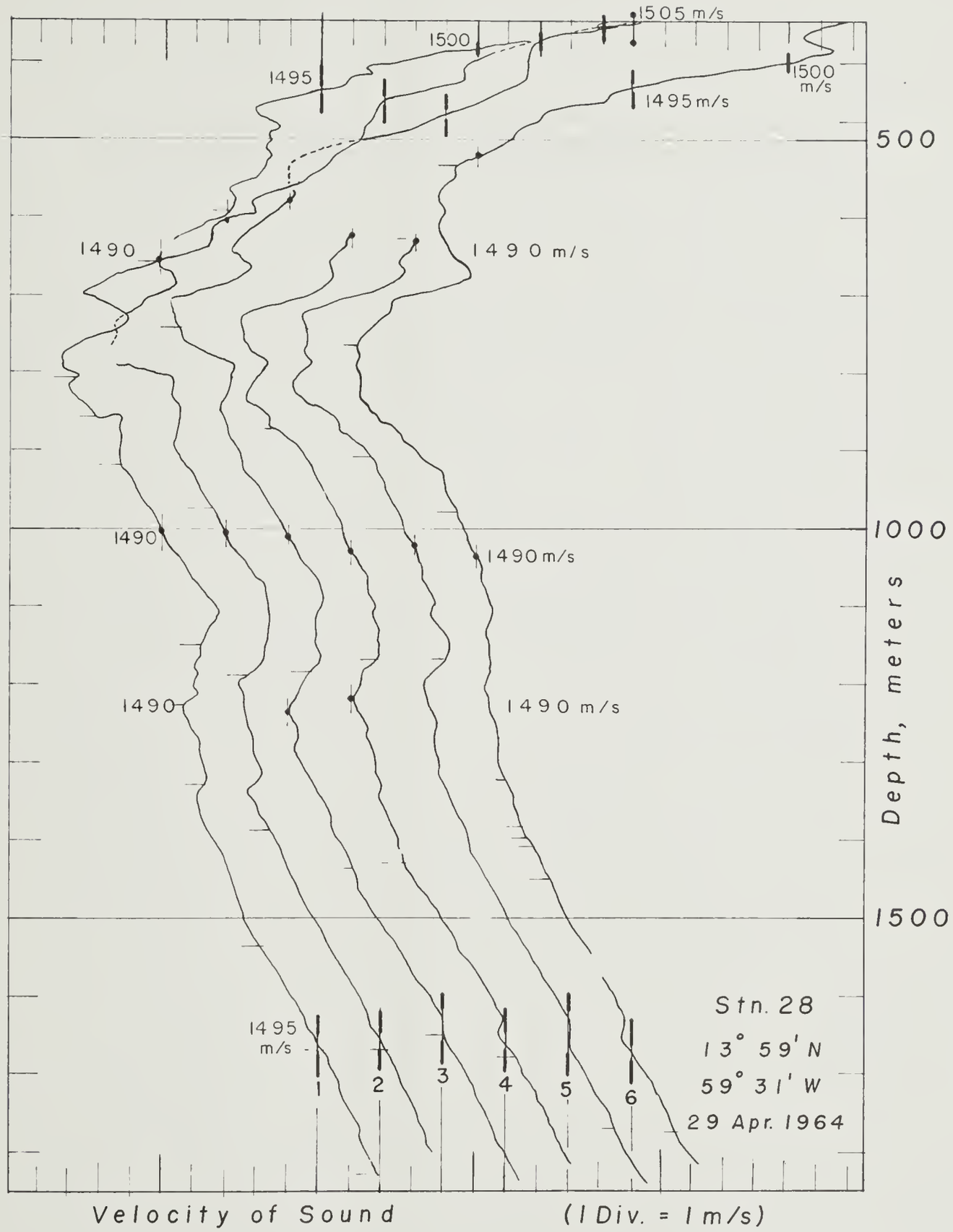


Fig. 16 Profile family, Station 28

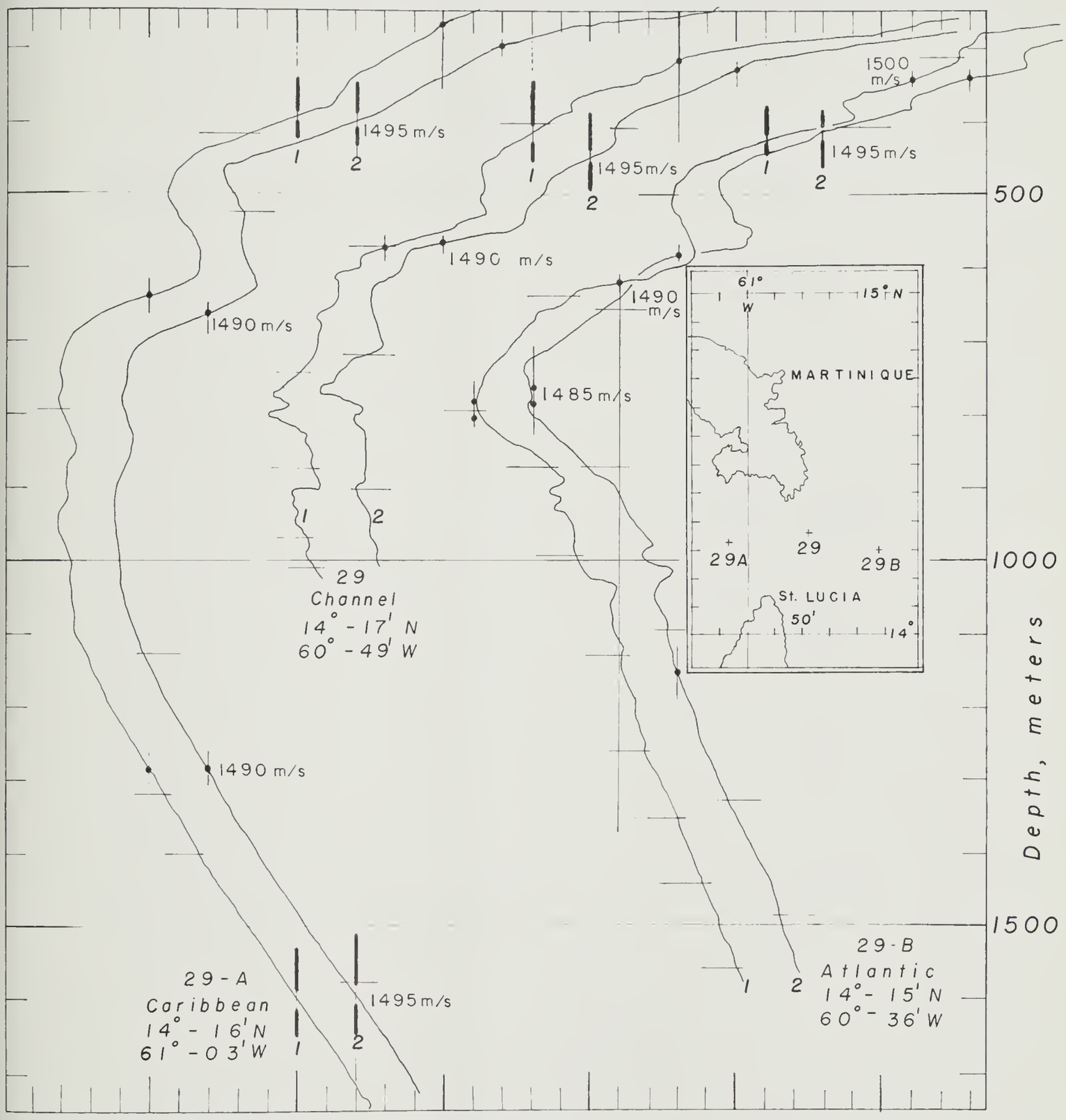


Fig.17 Profile family, Stations 29, 29A, 29B

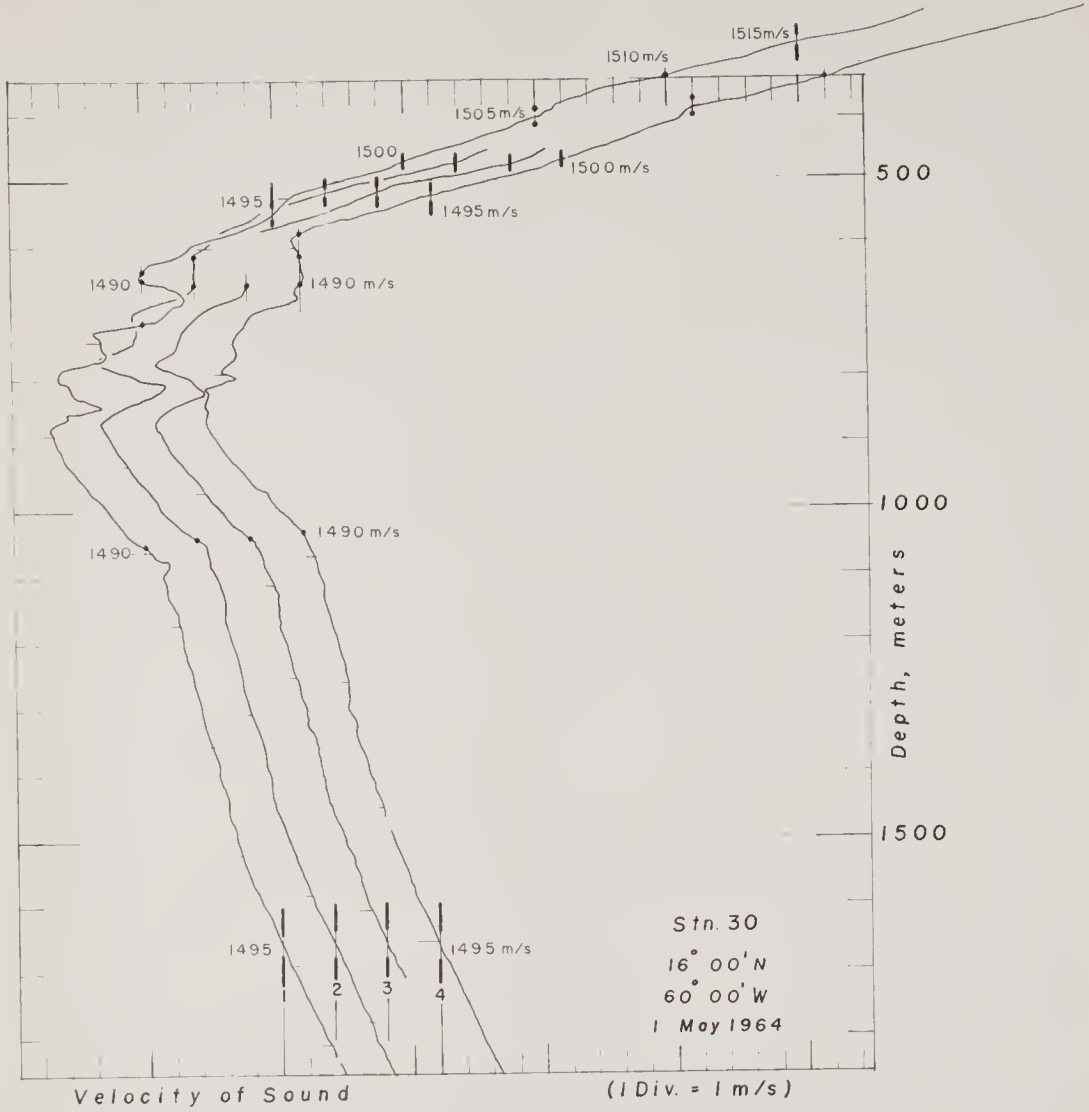


Fig. 18 Profile family, Station 30

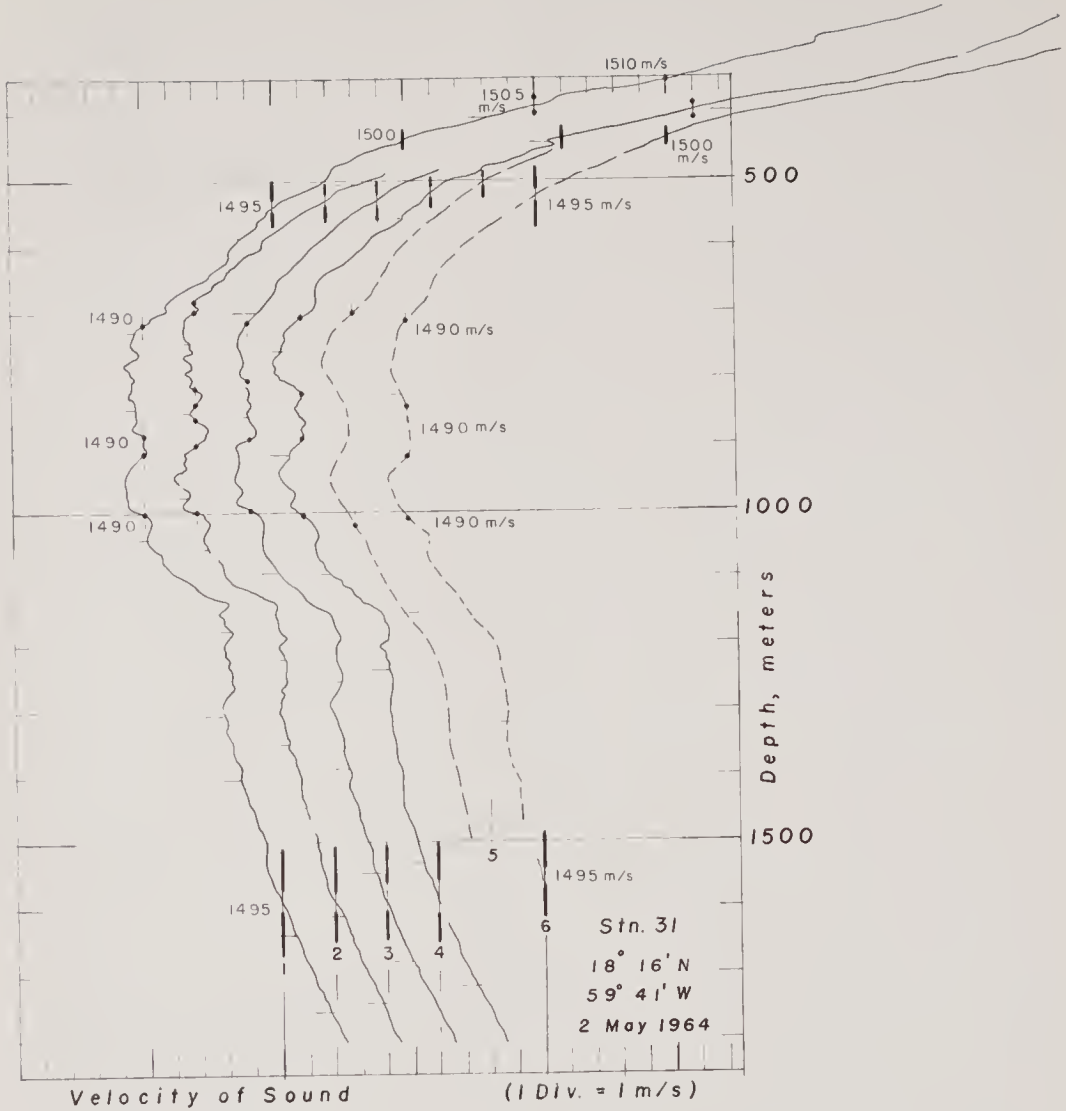


Fig.19 Profile family, Station 31

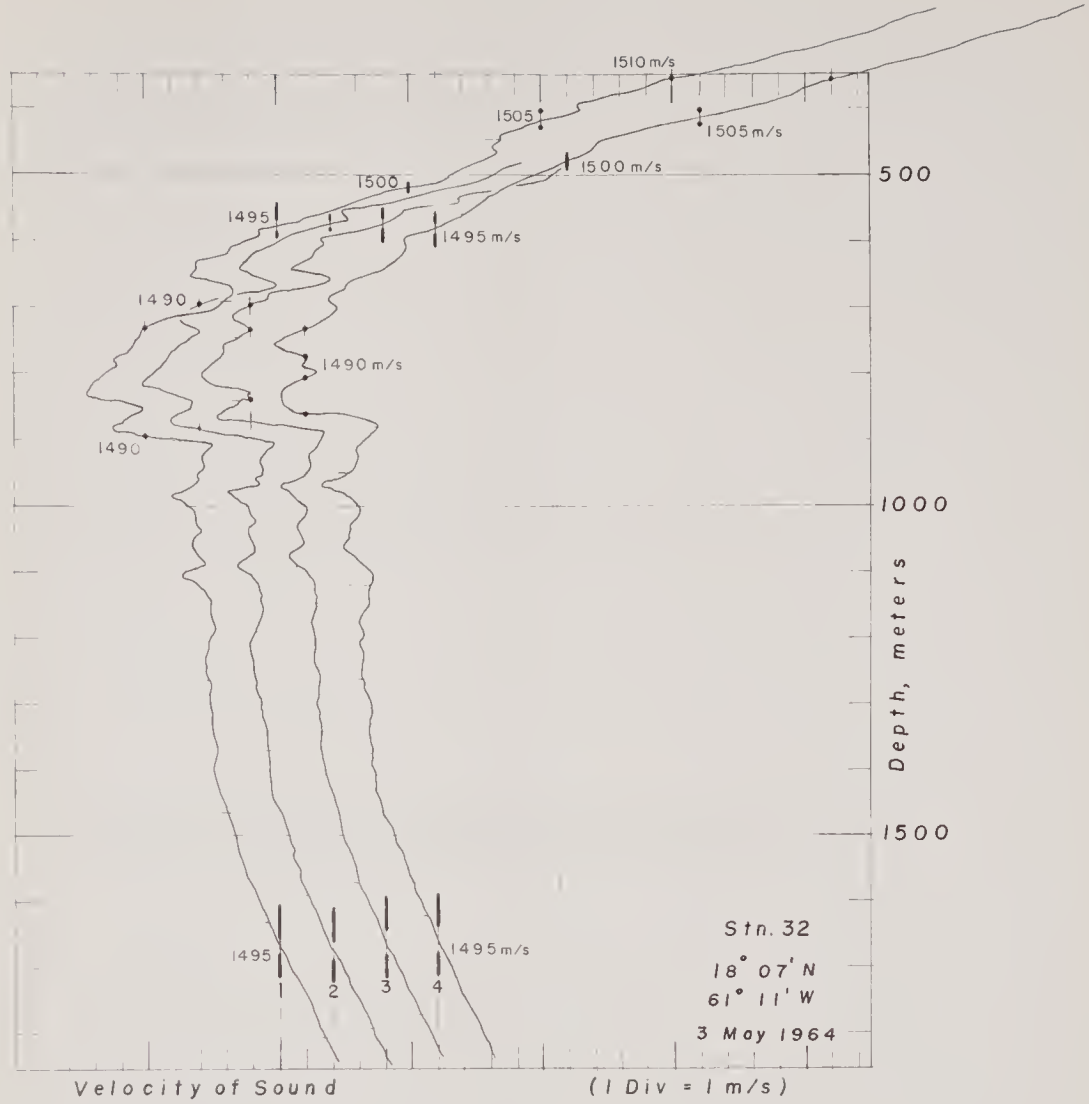


Fig.20 Profile family, Station 32

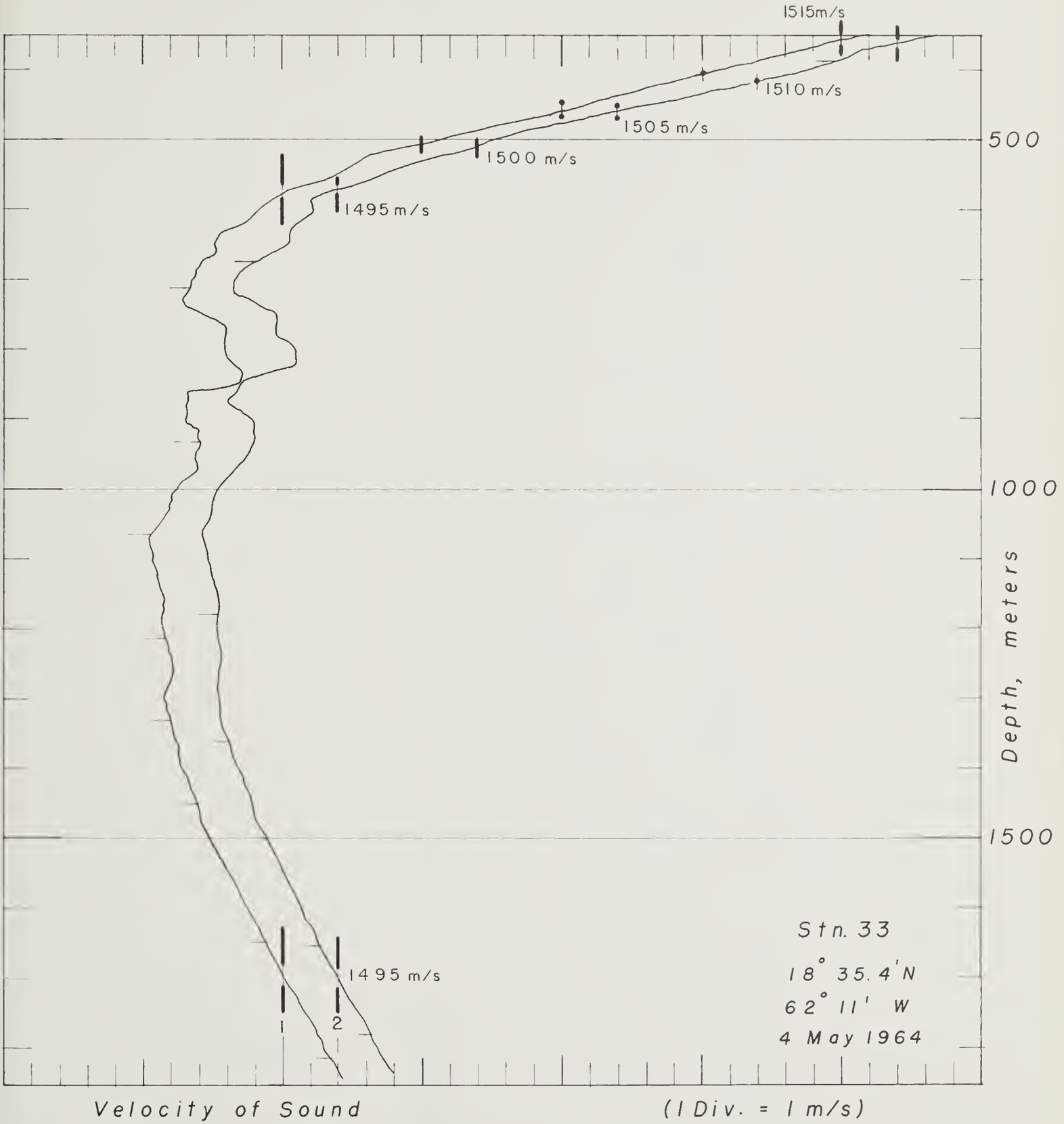


Fig. 21 Profile family, Station 33

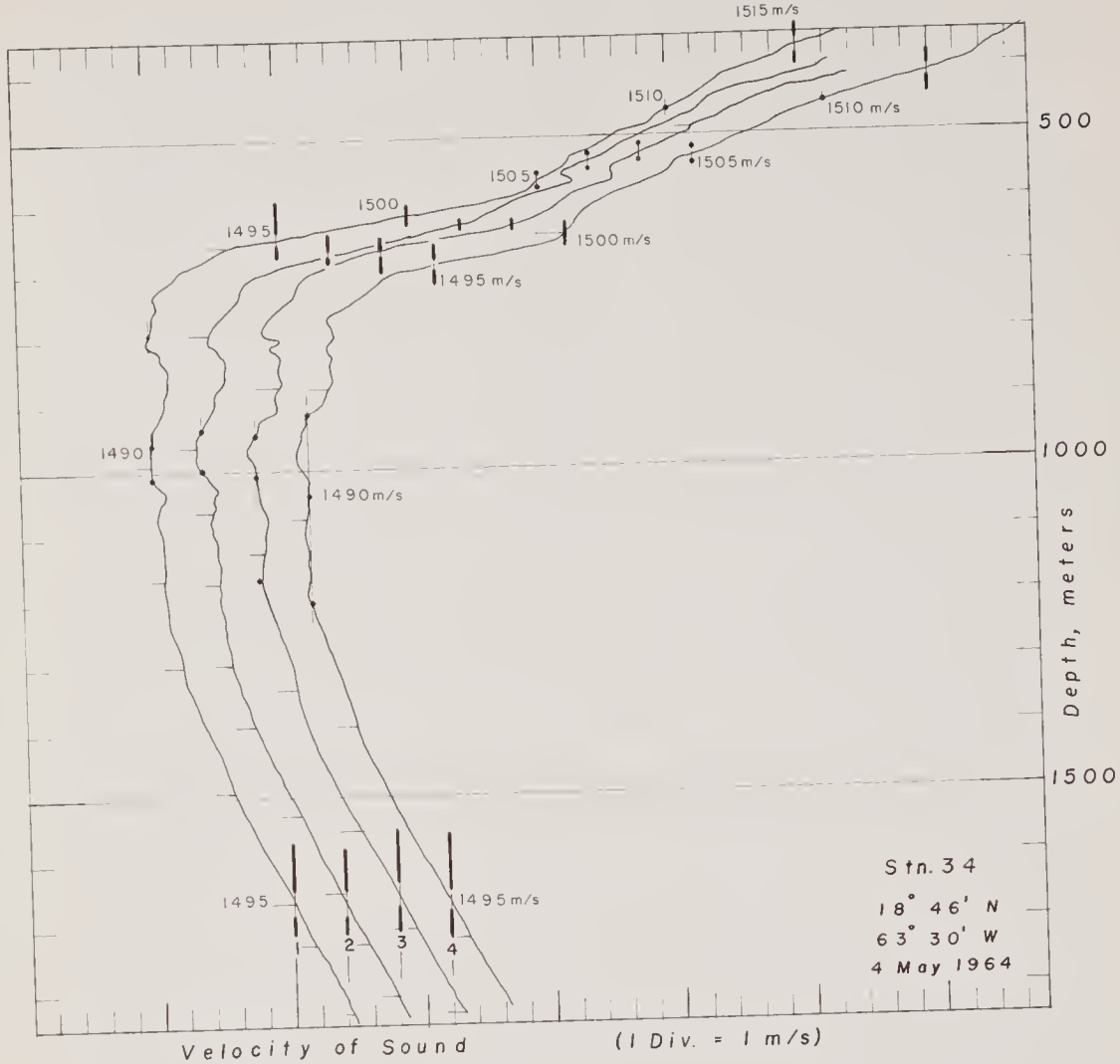


Fig.22 Profile family, Station 34

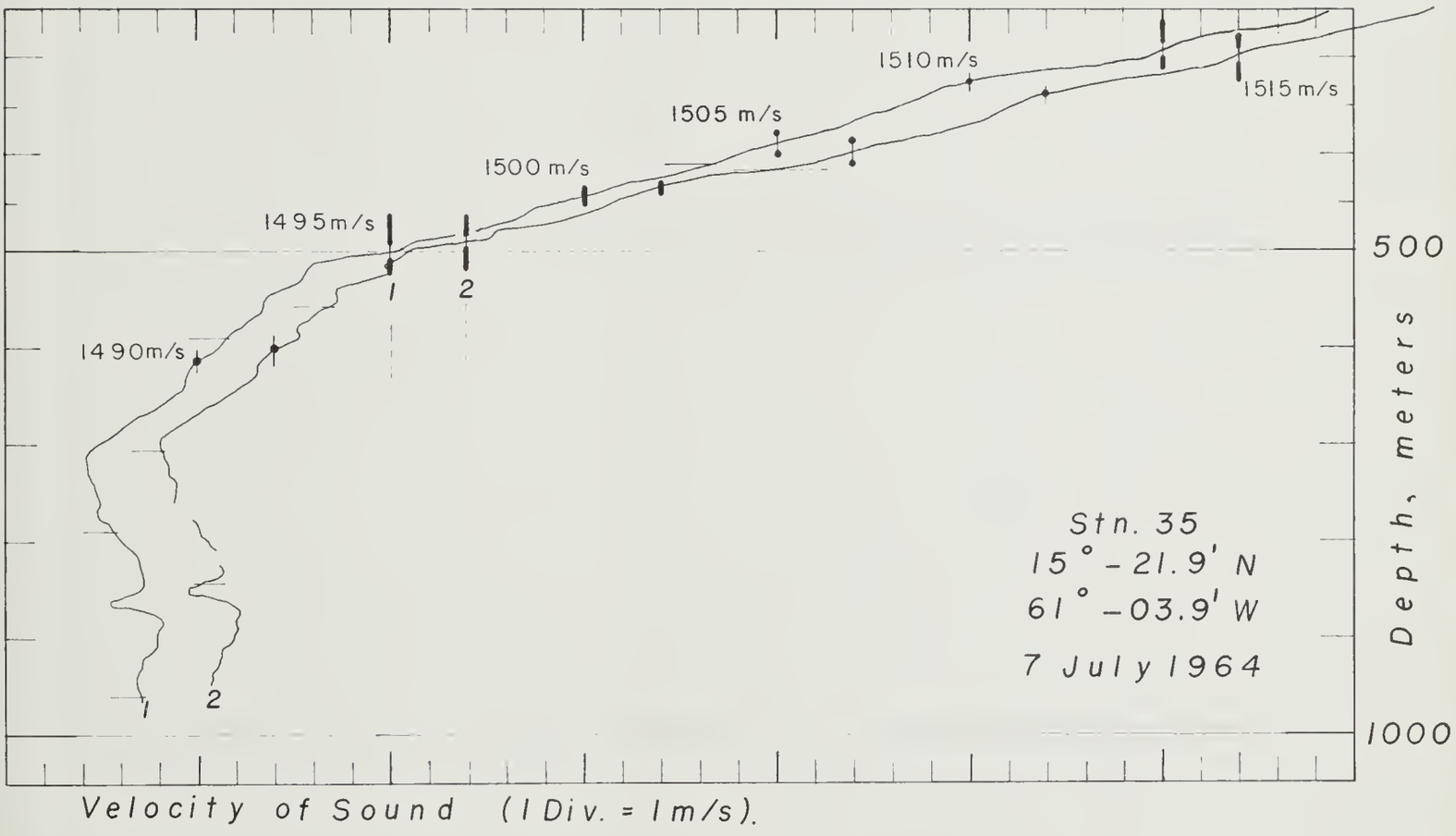


Fig.23 Profile family, Station 35

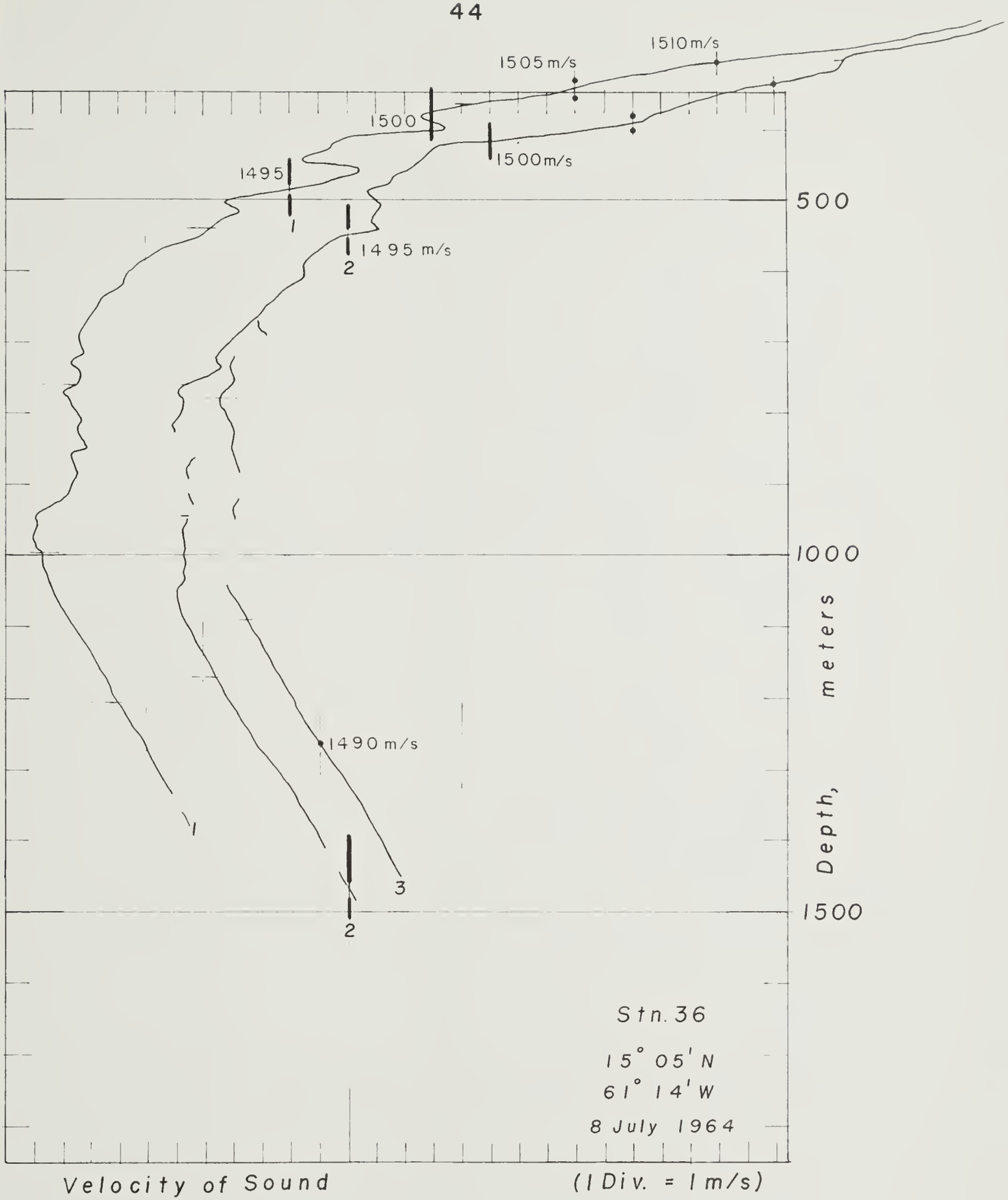


Fig. 24 Profile family, Station 36

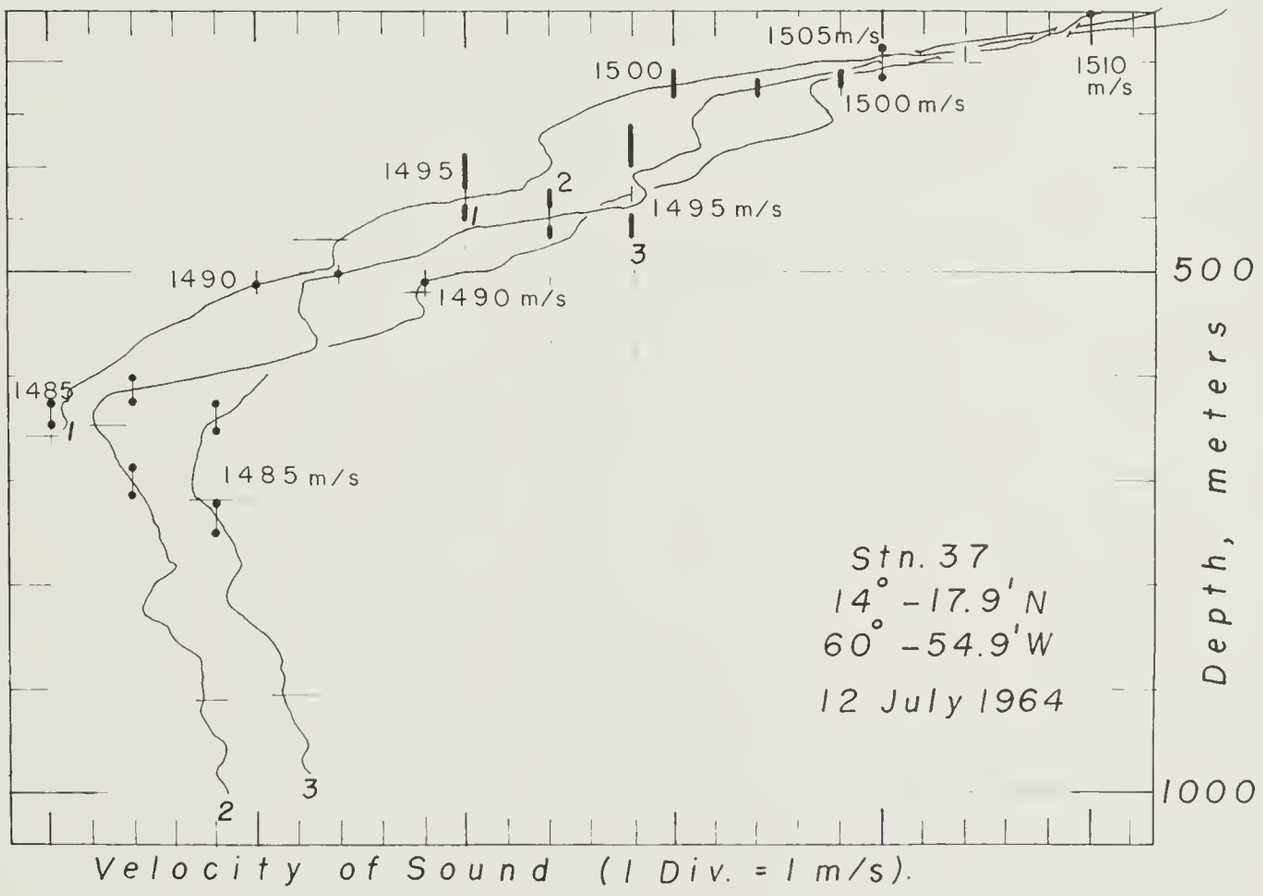


Fig. 25 Profile family, Station 37

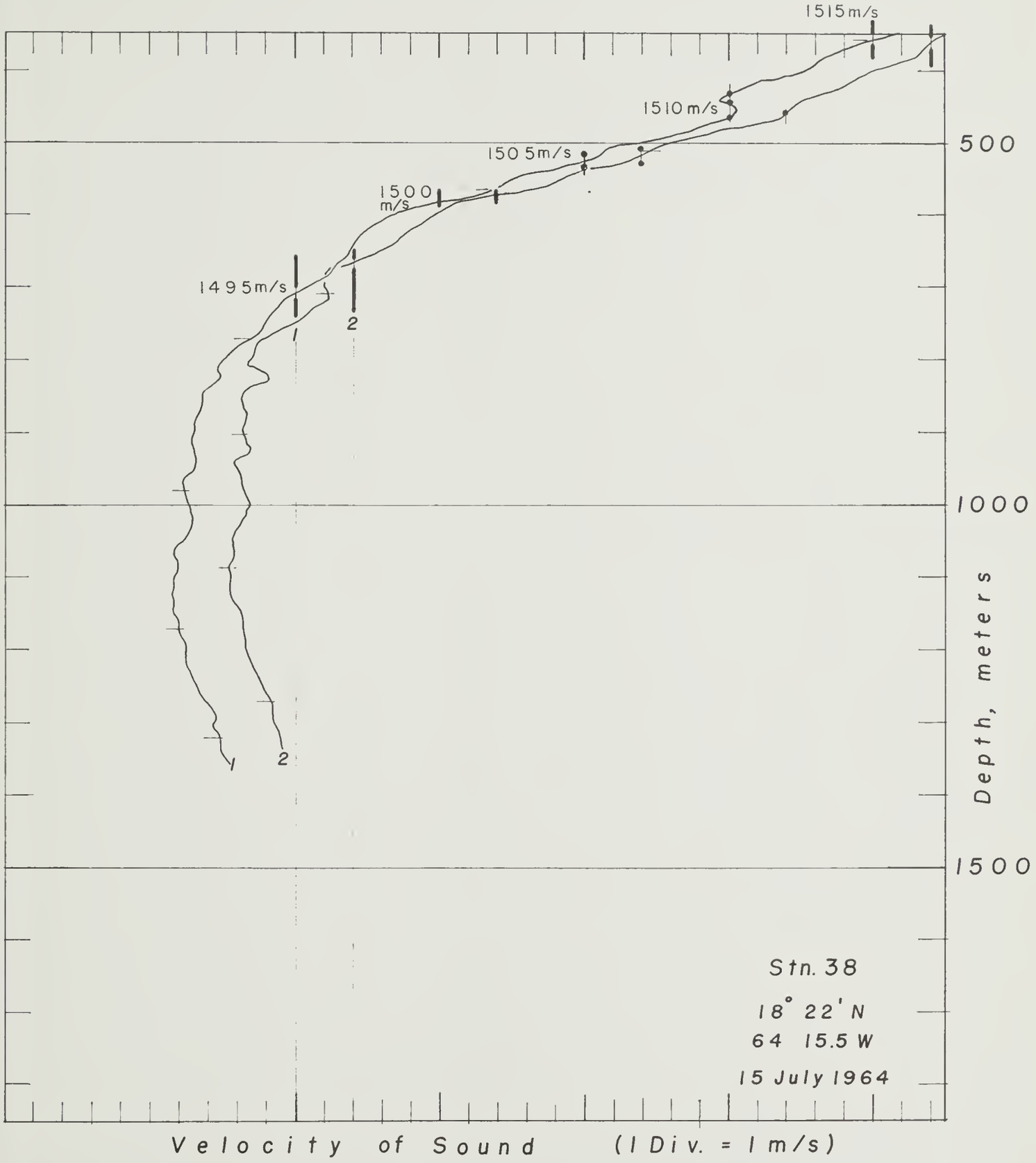


Fig. 26 Profile family, Station 38

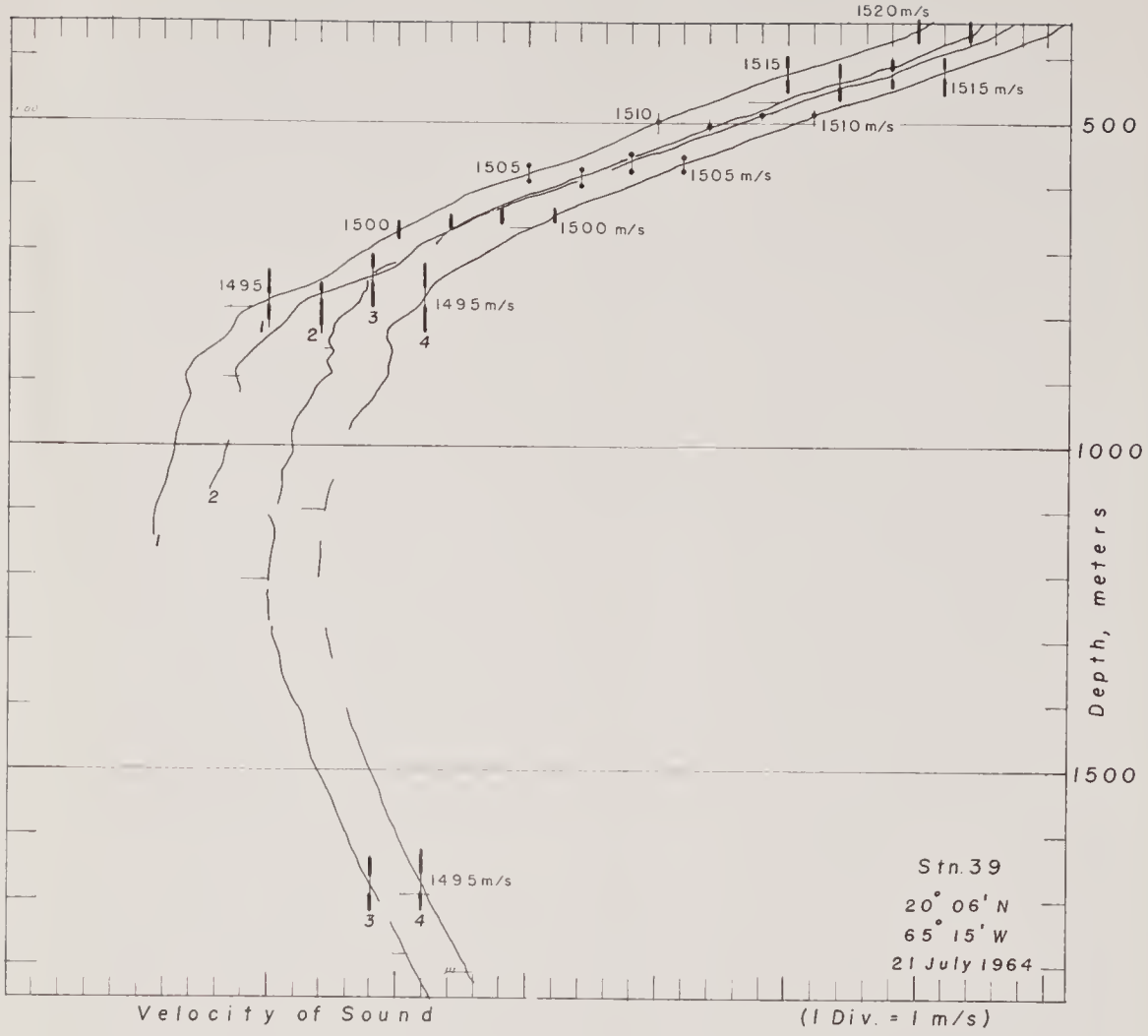


Fig. 27 Profile family, Station 39

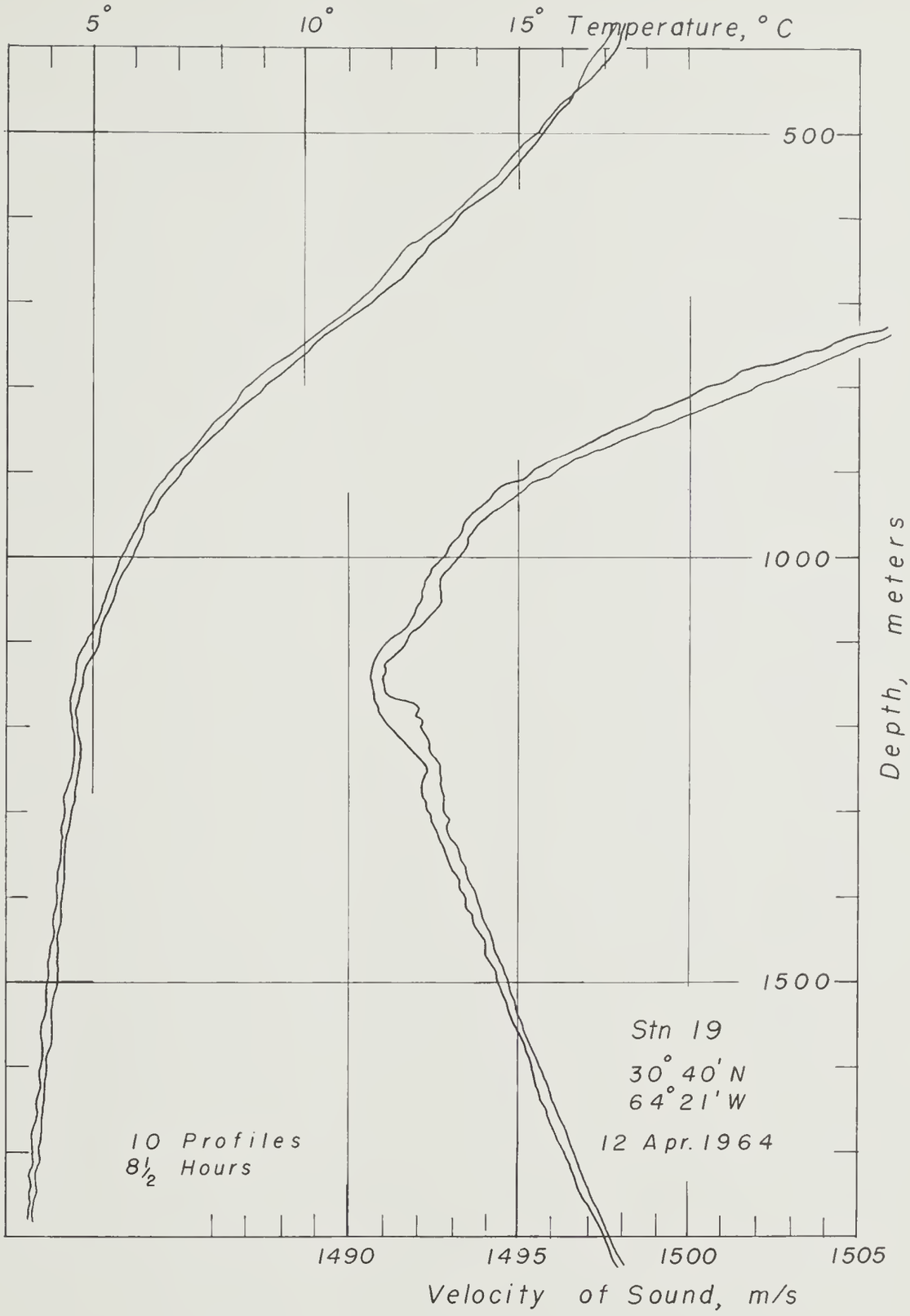


Fig. 28 Envelope of Profiles, Station 19

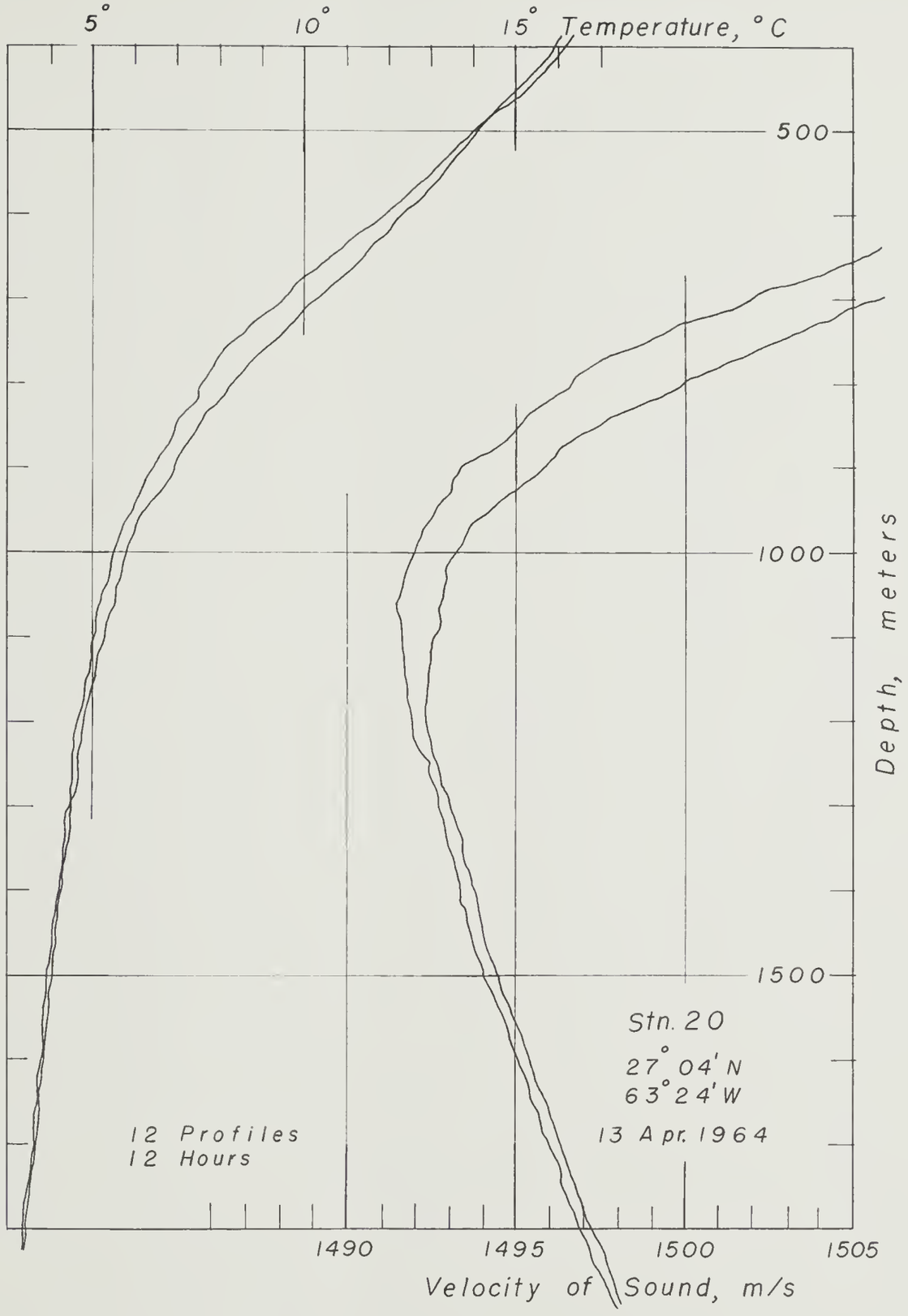


Fig. 29 Envelope of Profiles, Station 20

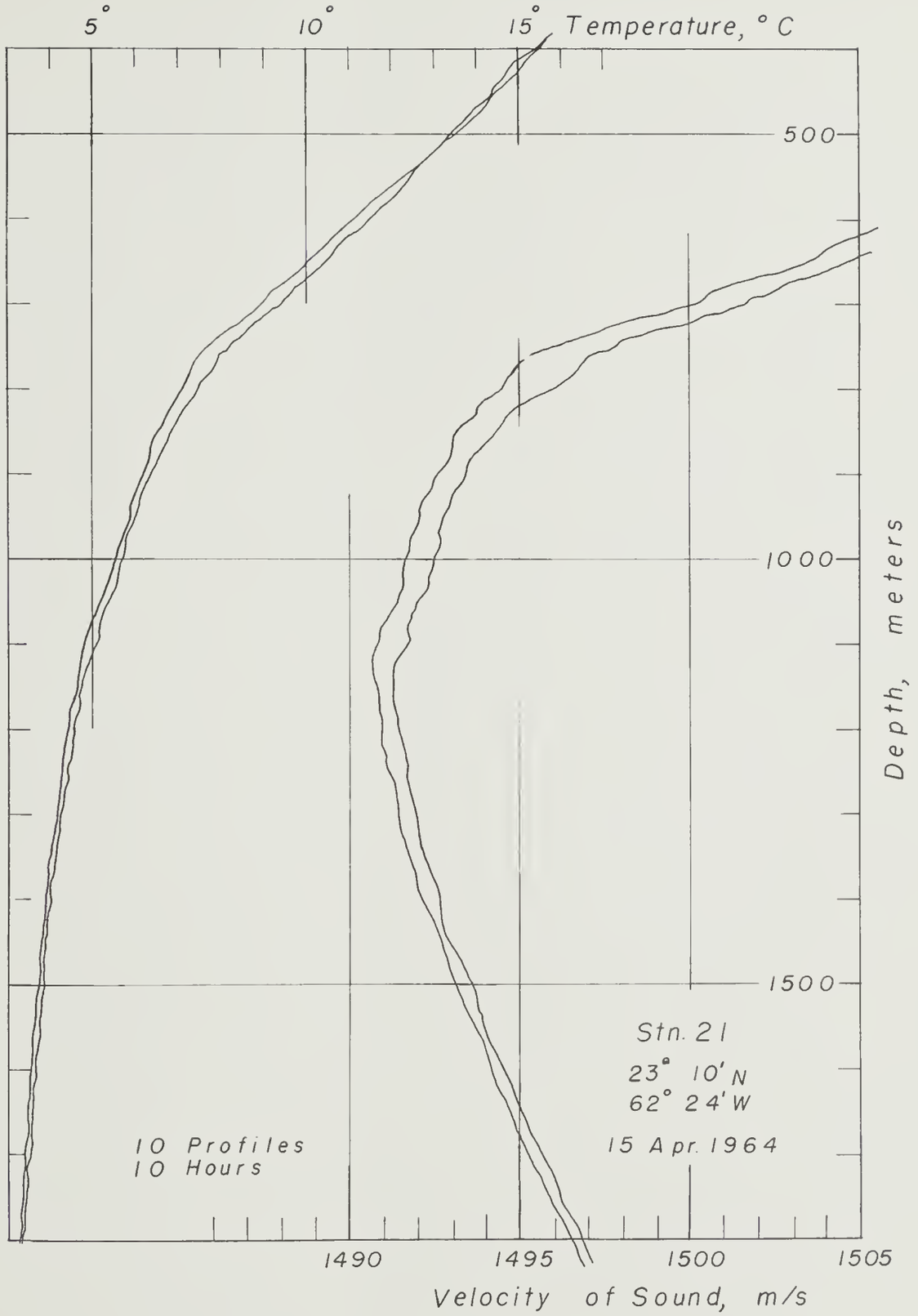


Fig. 30 Envelope of Profiles, Station 21

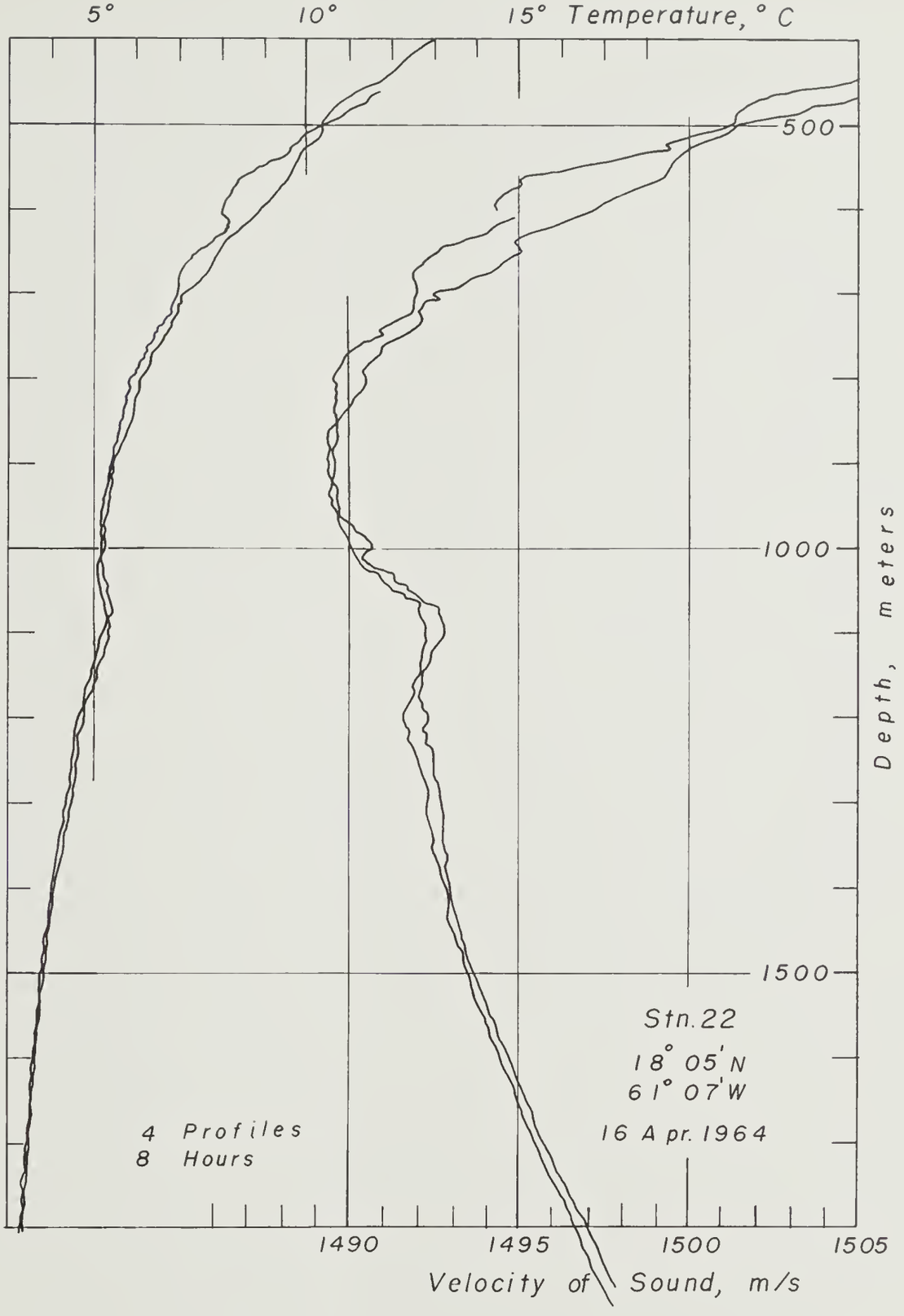


Fig. 31 Envelope of Profiles, Station 22

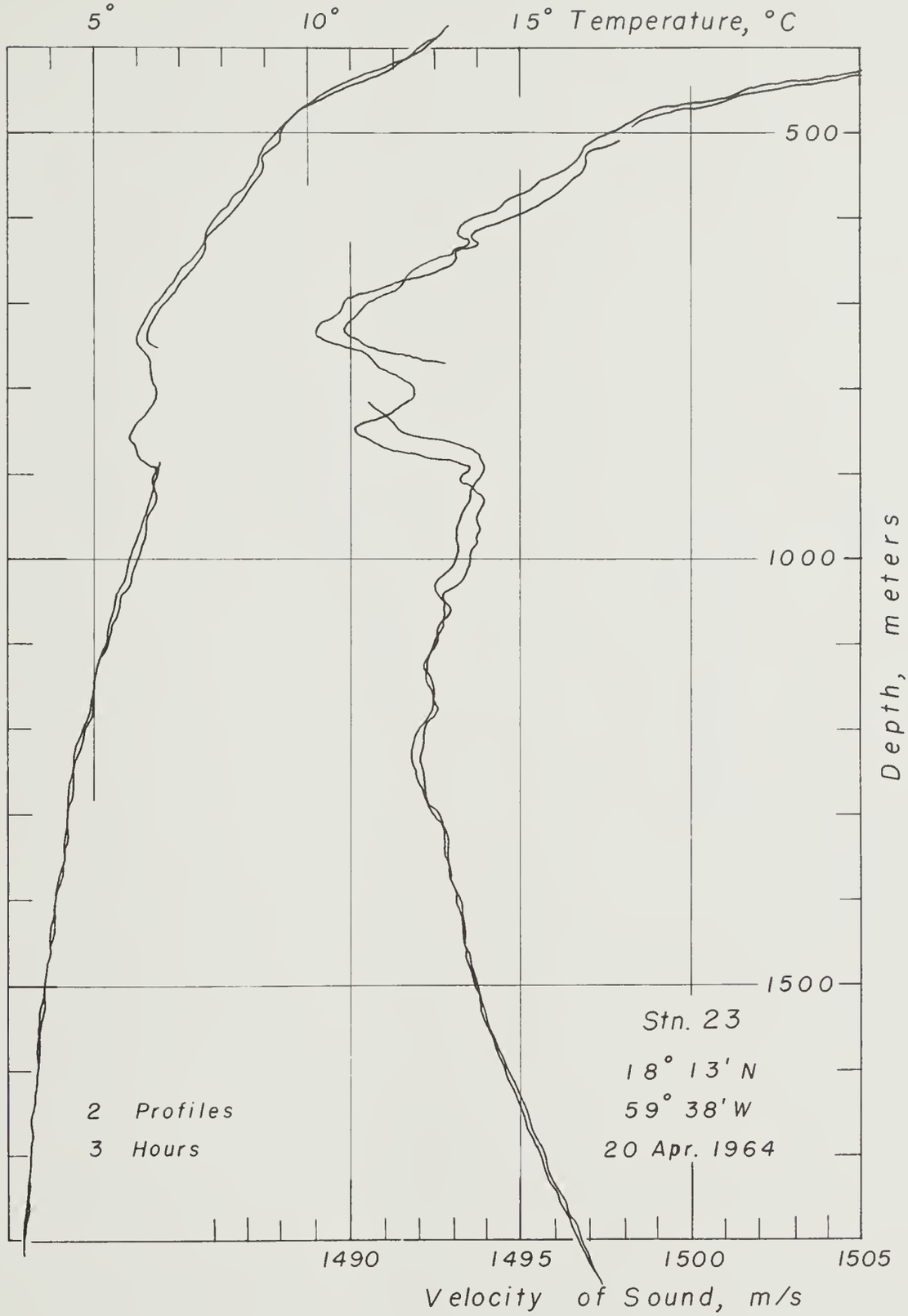


Fig. 32 Envelope of Profiles, Station 23

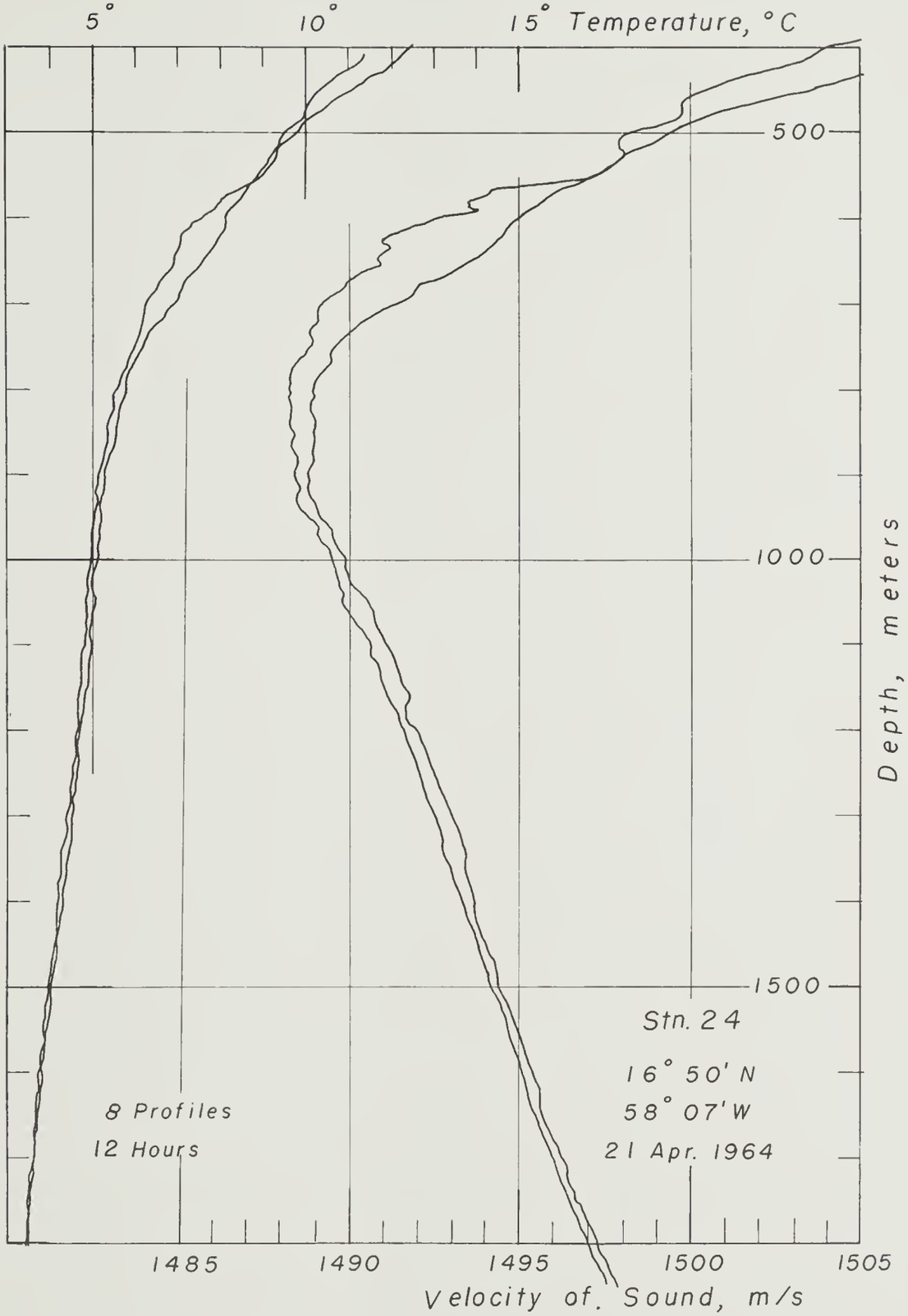


Fig. 33 Envelope of Profiles, Station 24

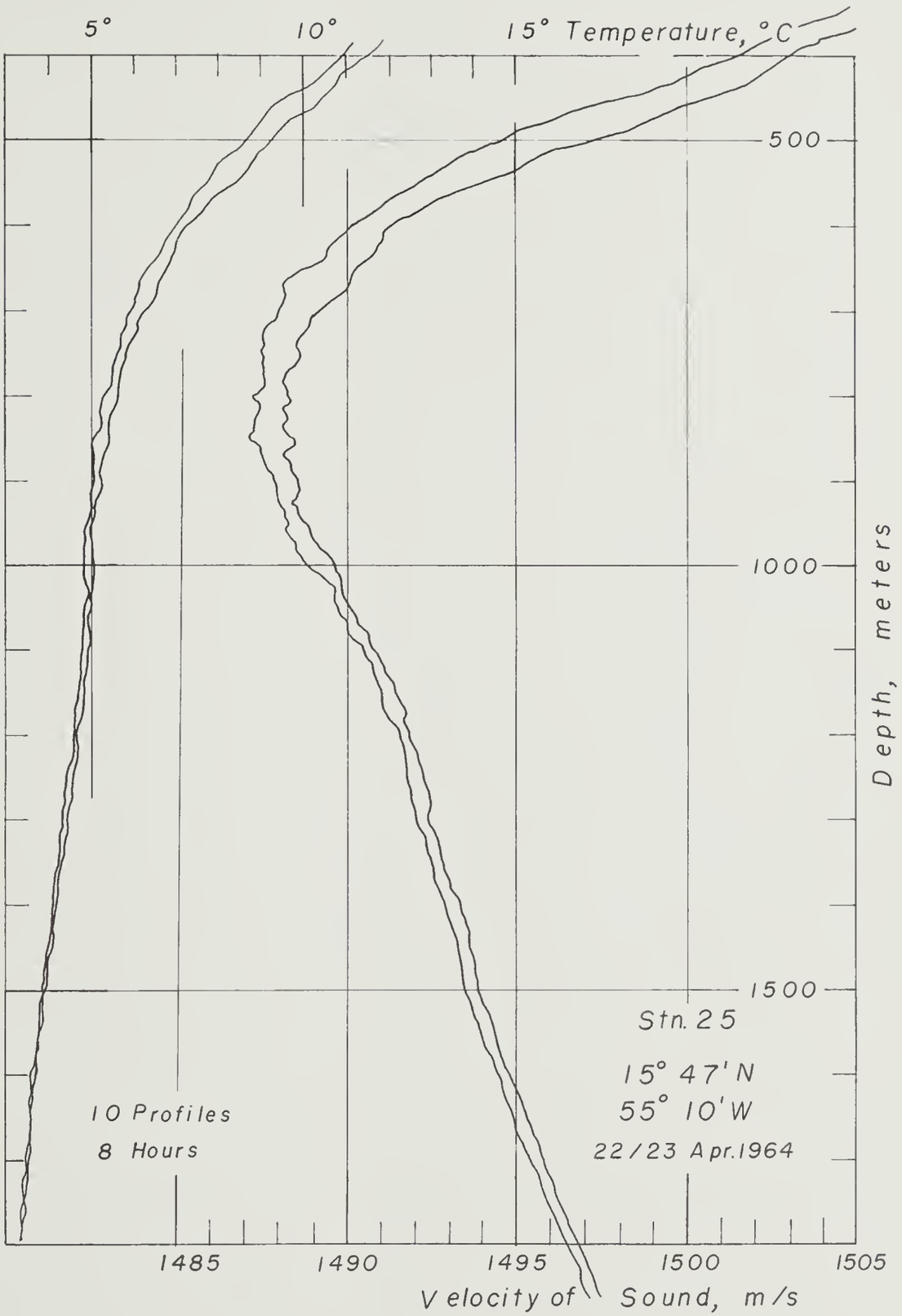


Fig. 34 Envelope of Profiles, Station 25

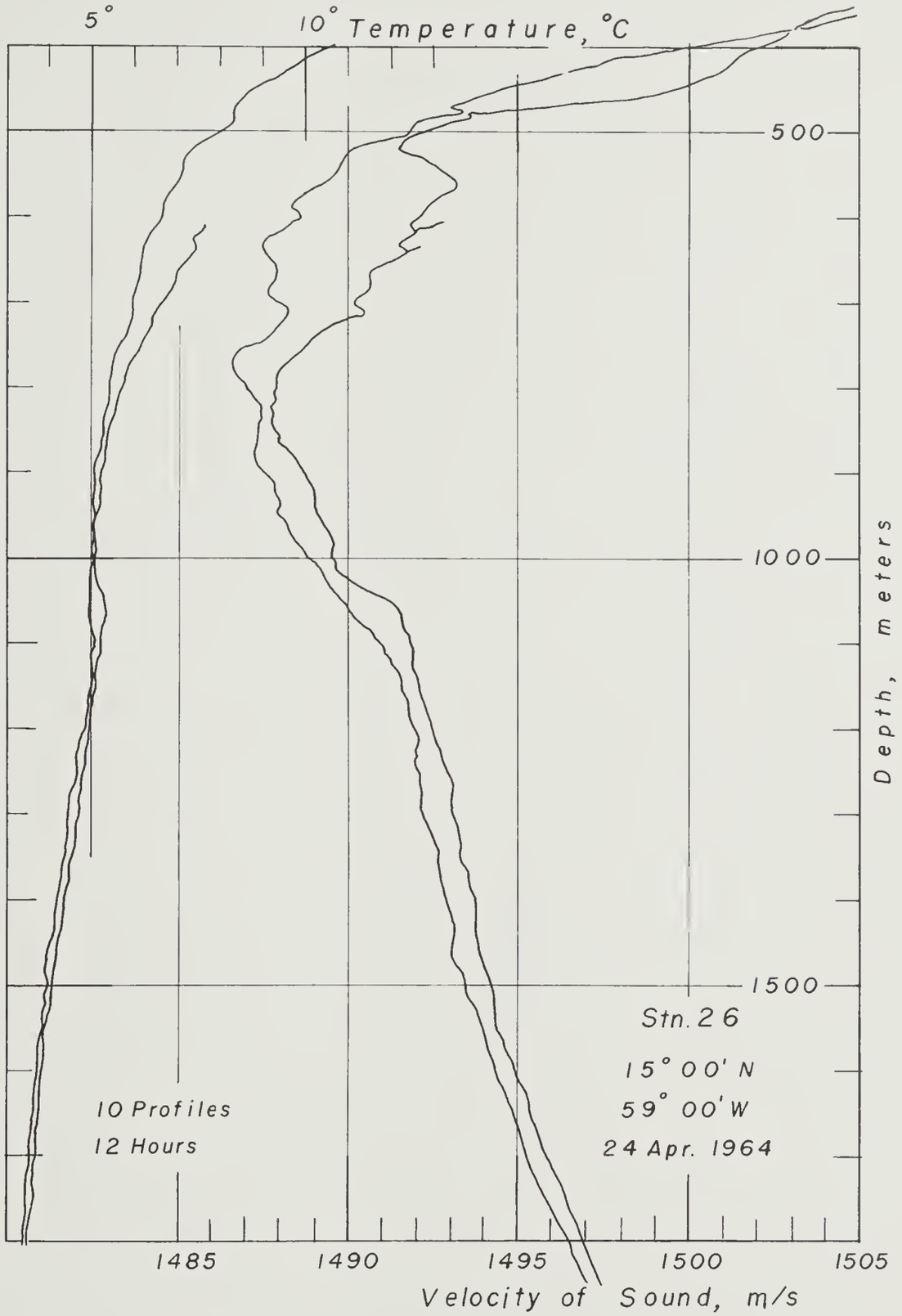


Fig. 35 Envelope of Profiles, Station 26

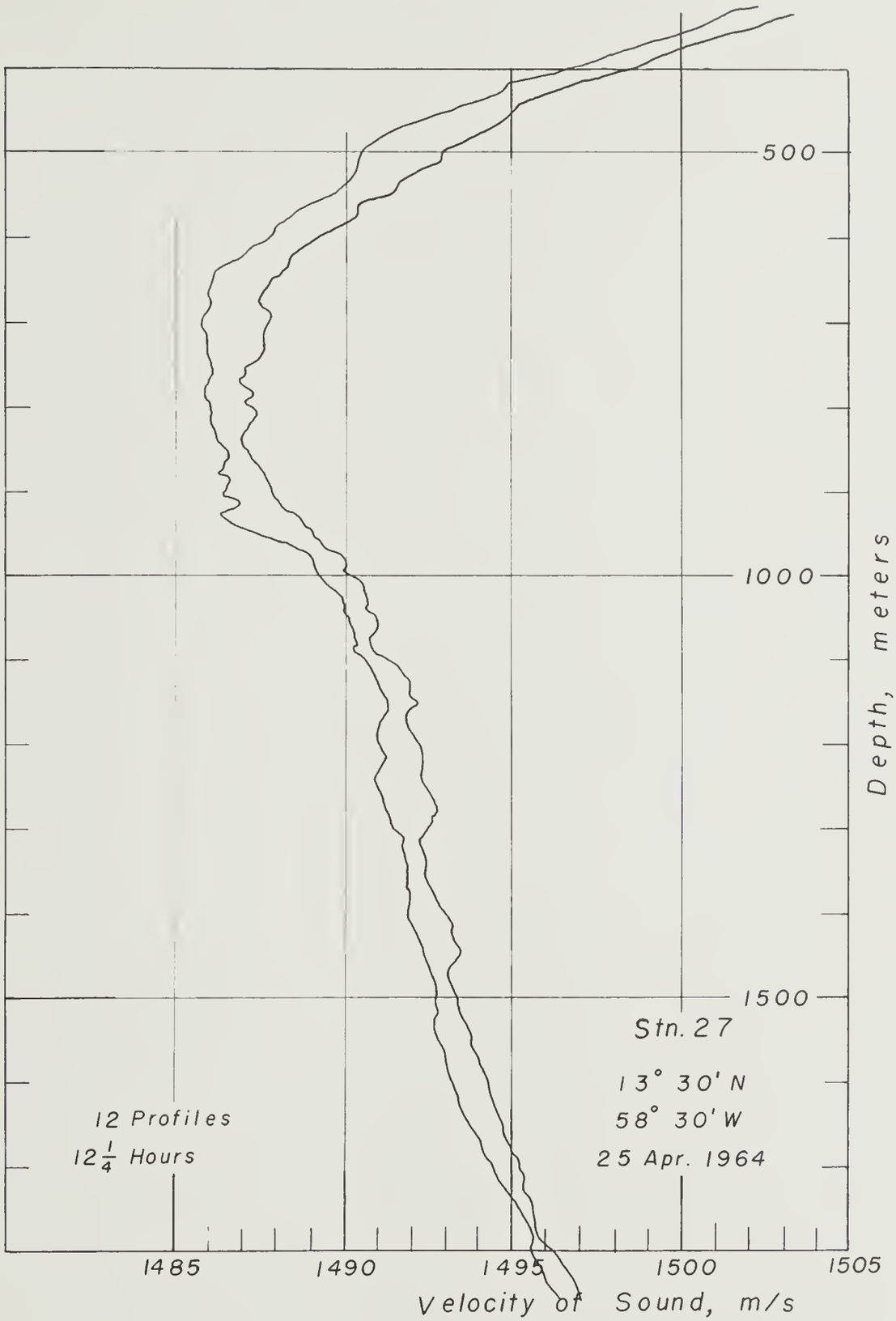


Fig. 36 Envelope of Profiles, Station 27

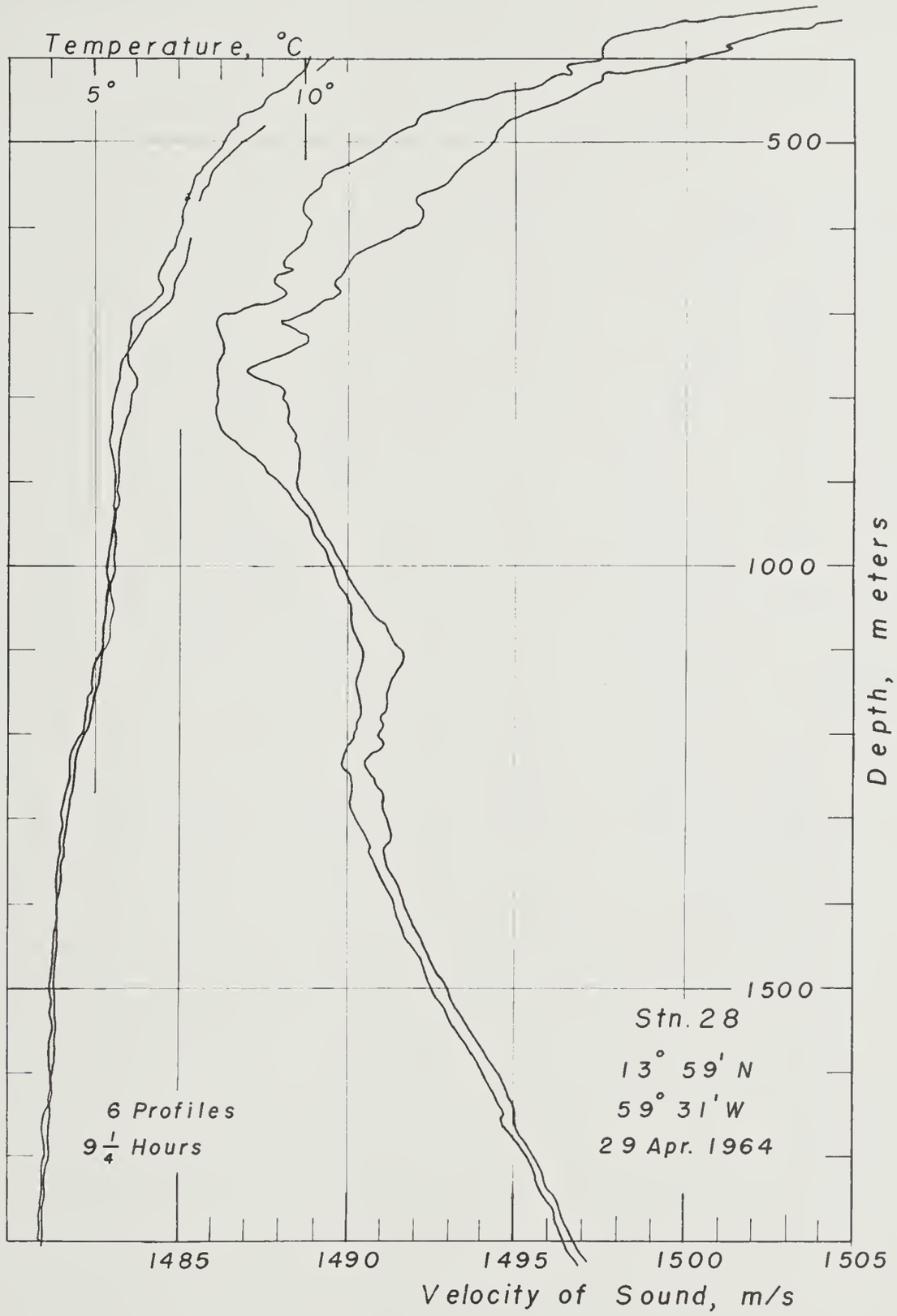


Fig.37 Envelope of Profiles, Station 28

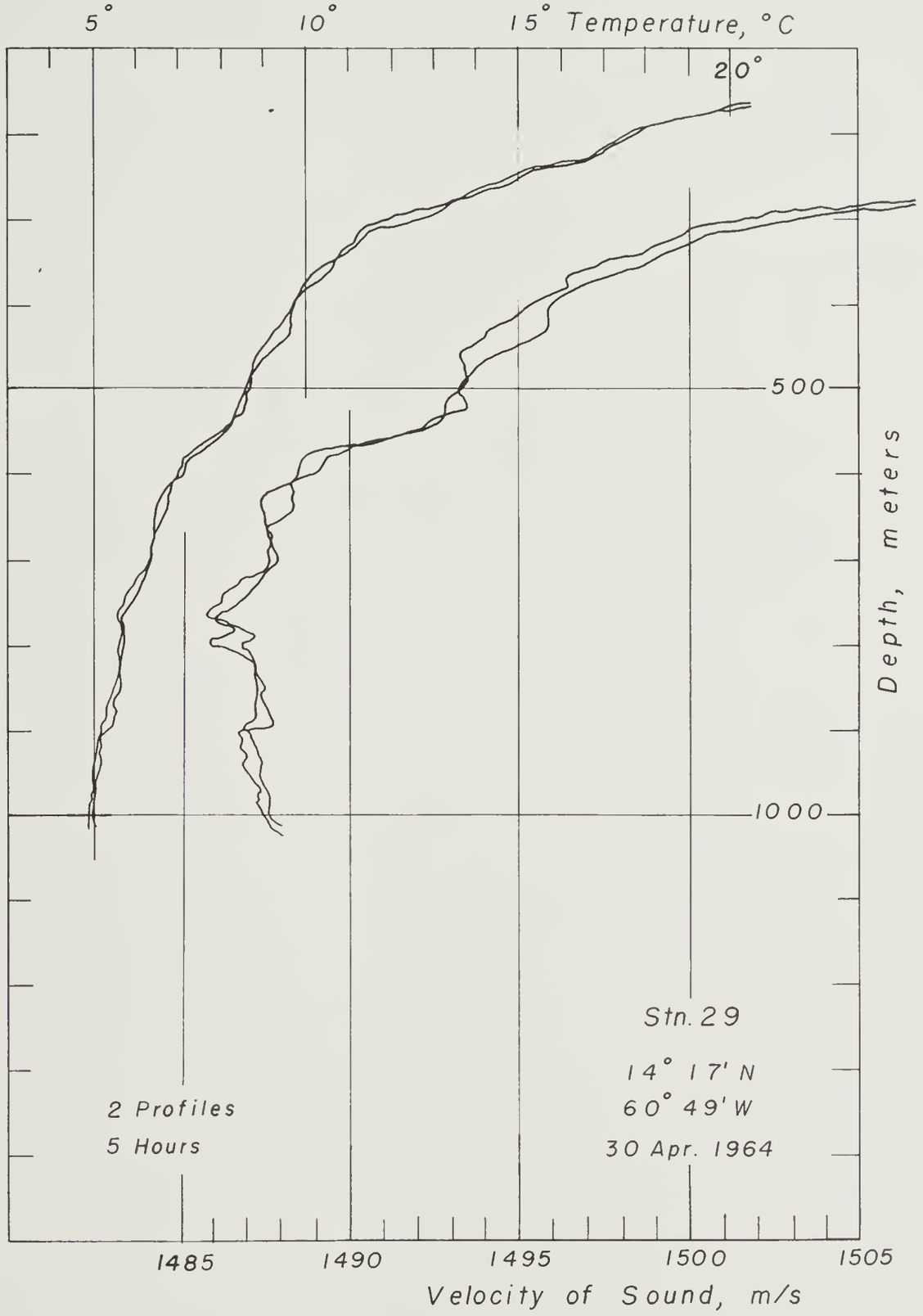


Fig. 38 Envelope of Profiles, Station 29

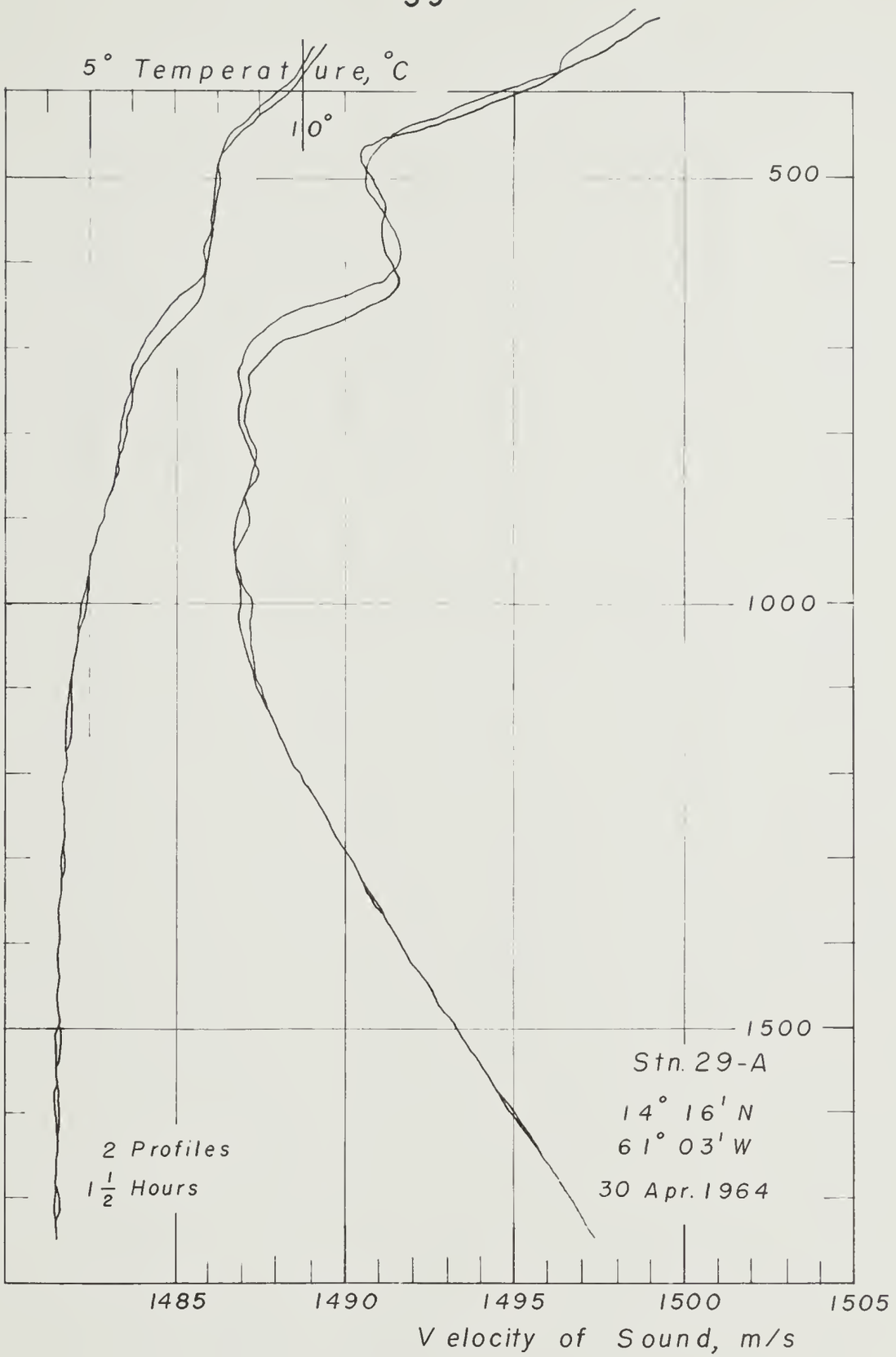


Fig. 39 Envelope of Profiles, Station 29A

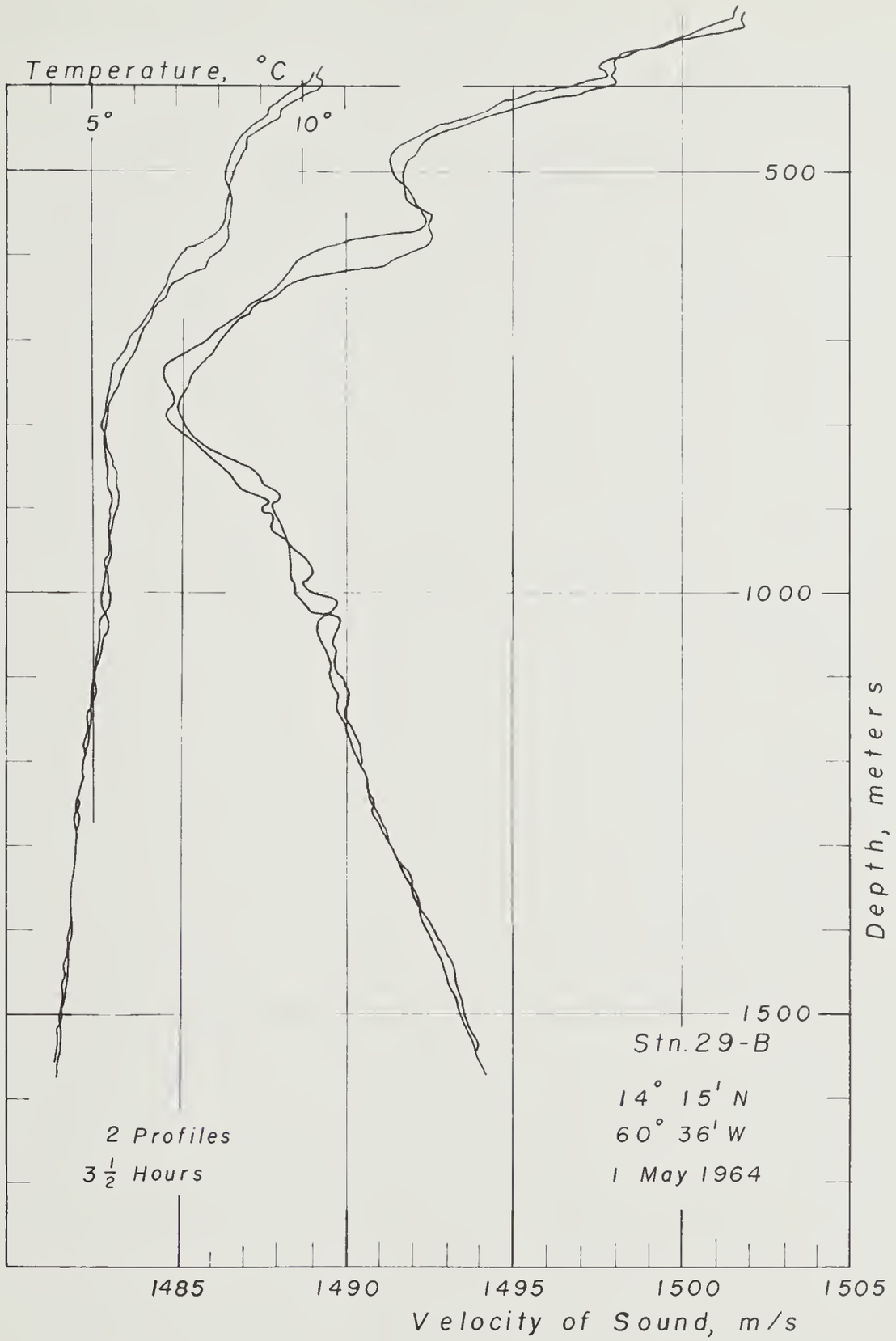


Fig. 40 Envelope of Profiles, Station 30B

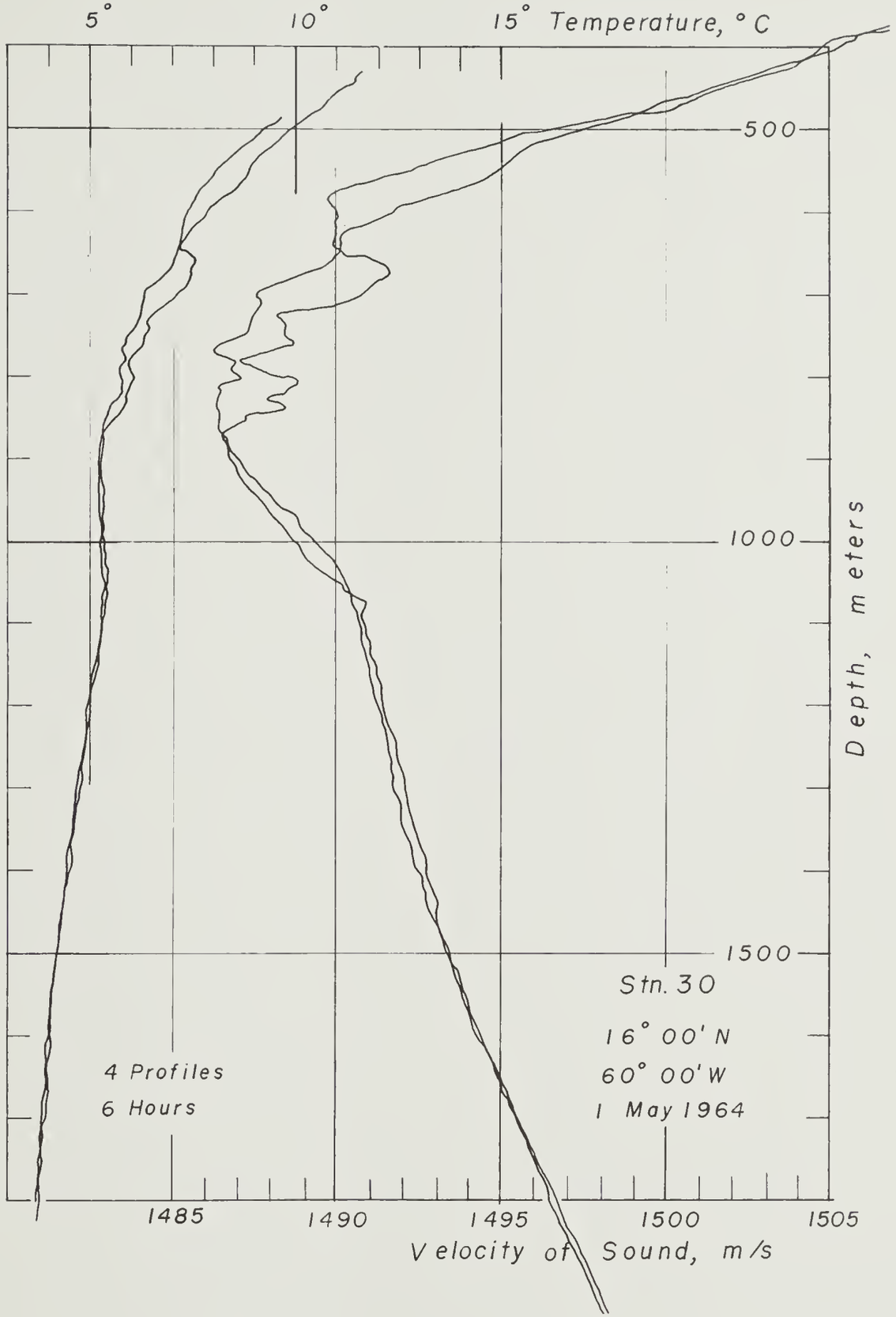


Fig. 41 Envelope of Profiles, Station 30

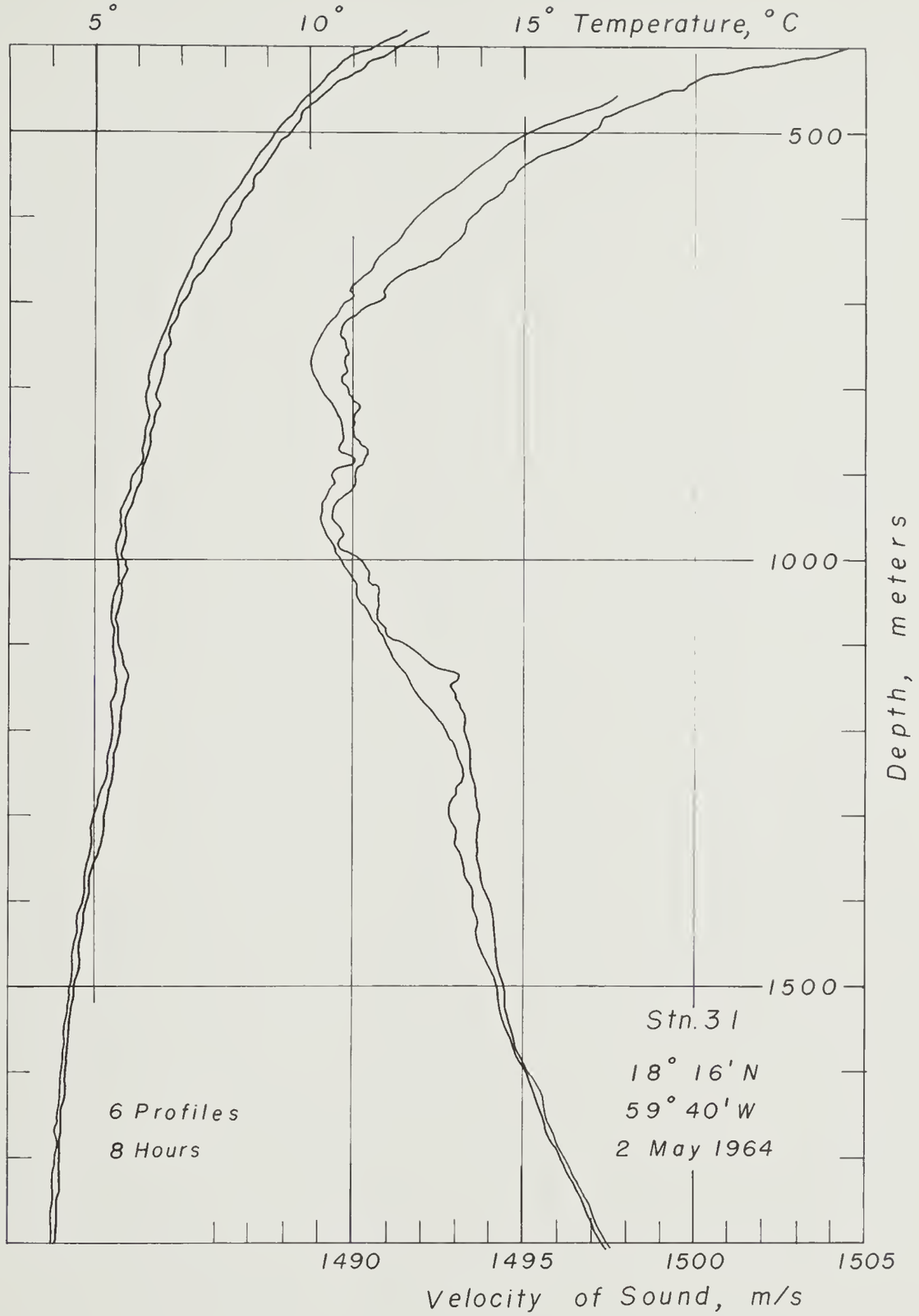


Fig. 42 Envelope of Profiles, Station 31

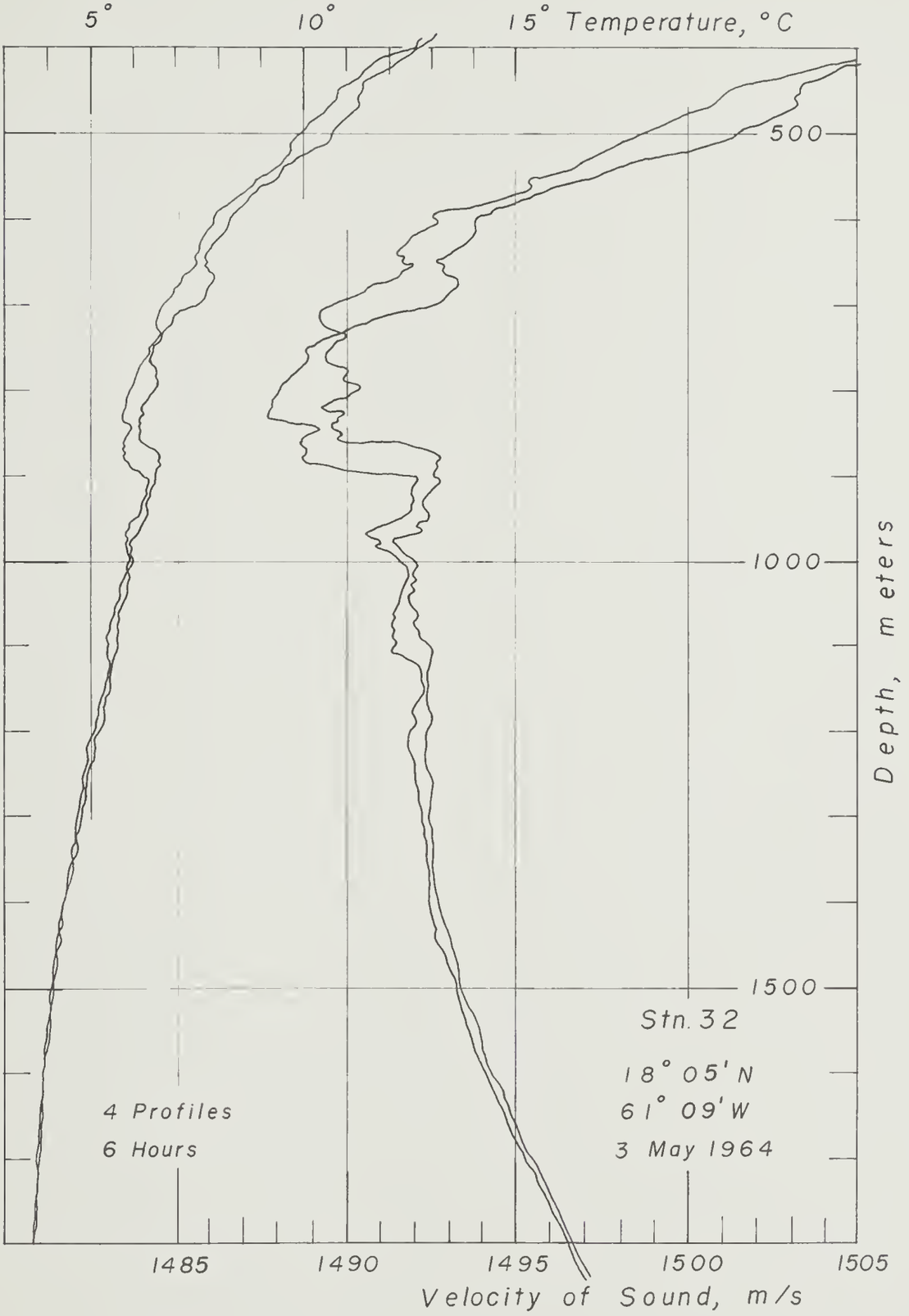


Fig. 43 Envelope of Profiles, Station 32

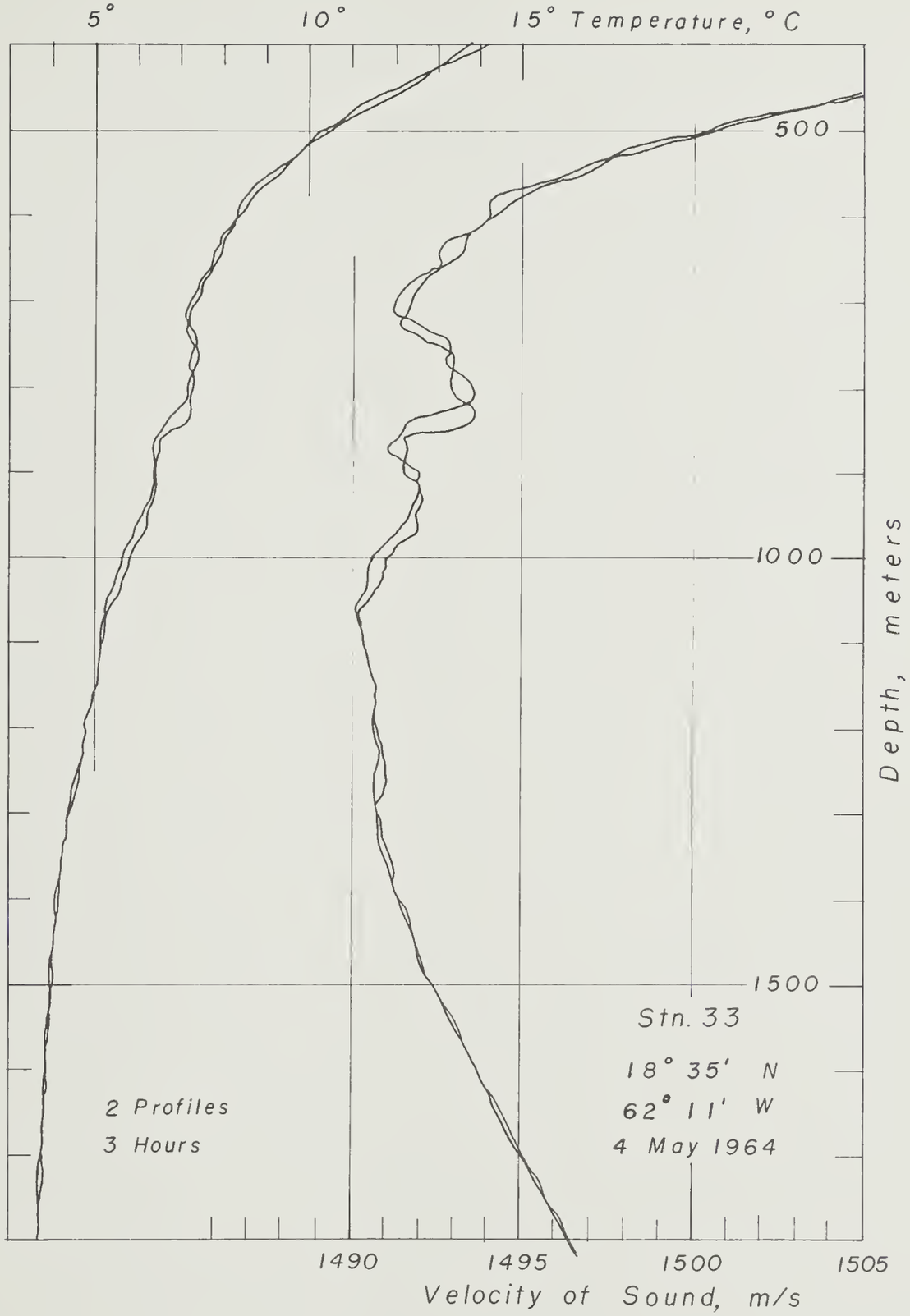
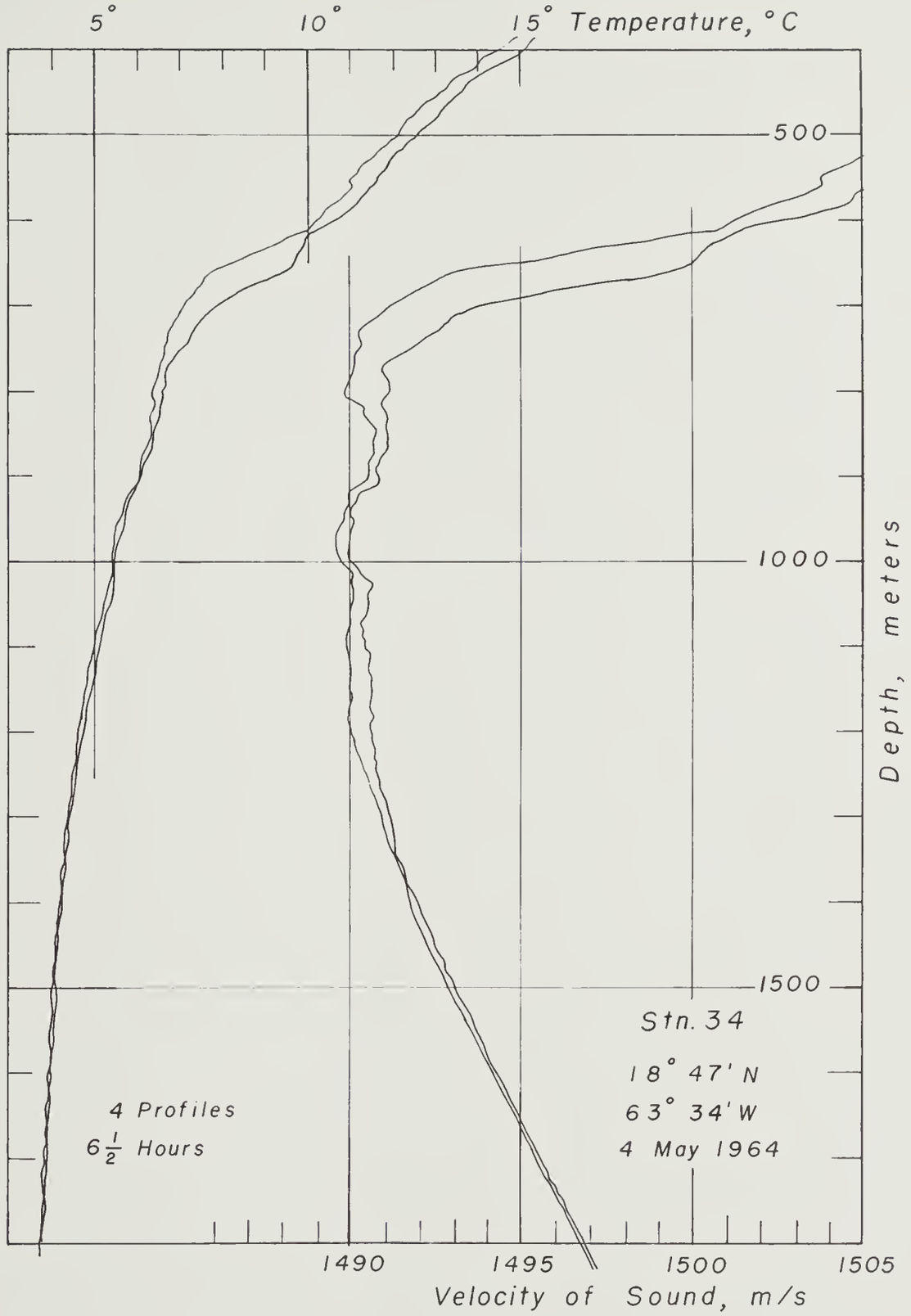


Fig. 44 Envelope of Profiles, Station 33



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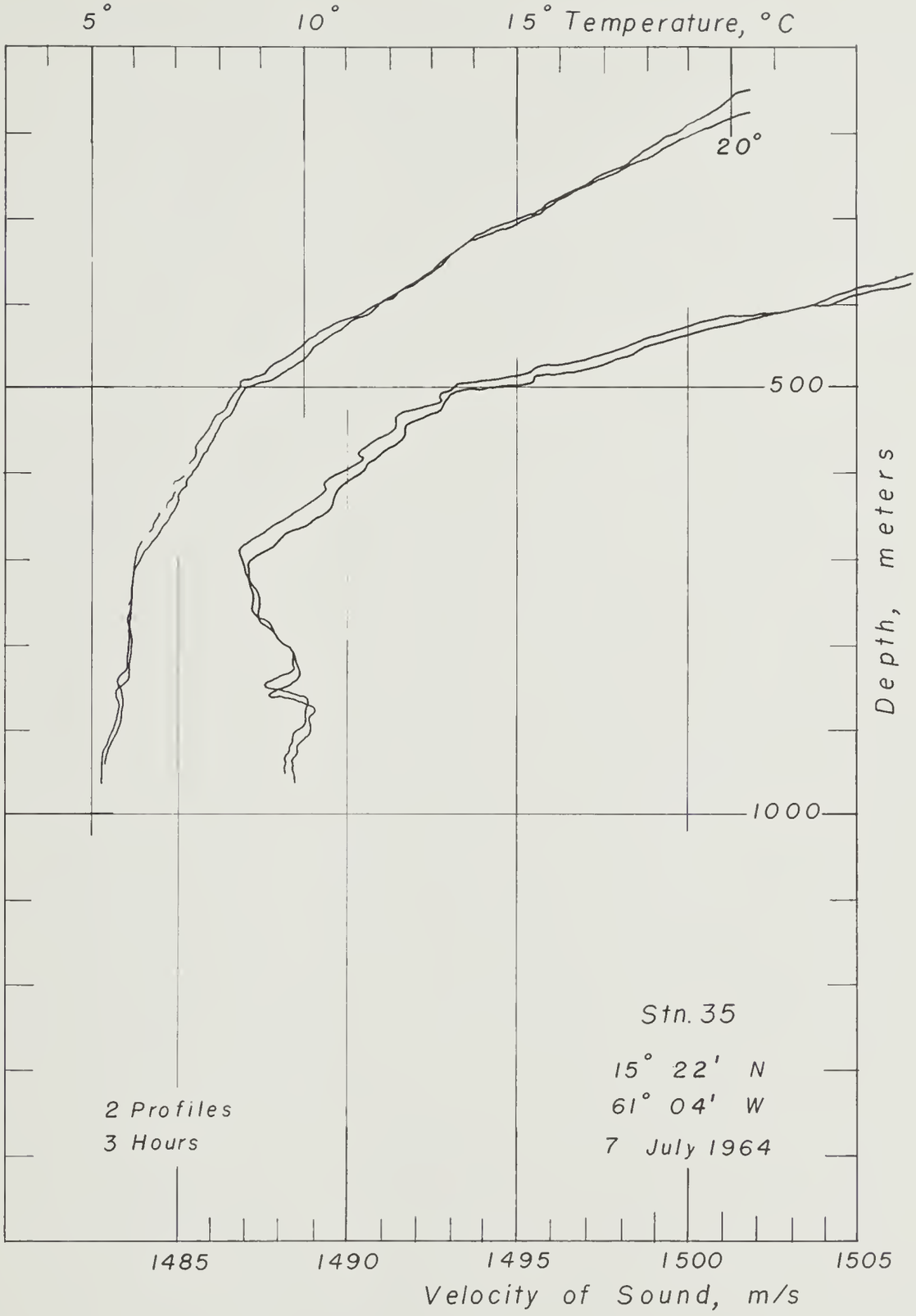

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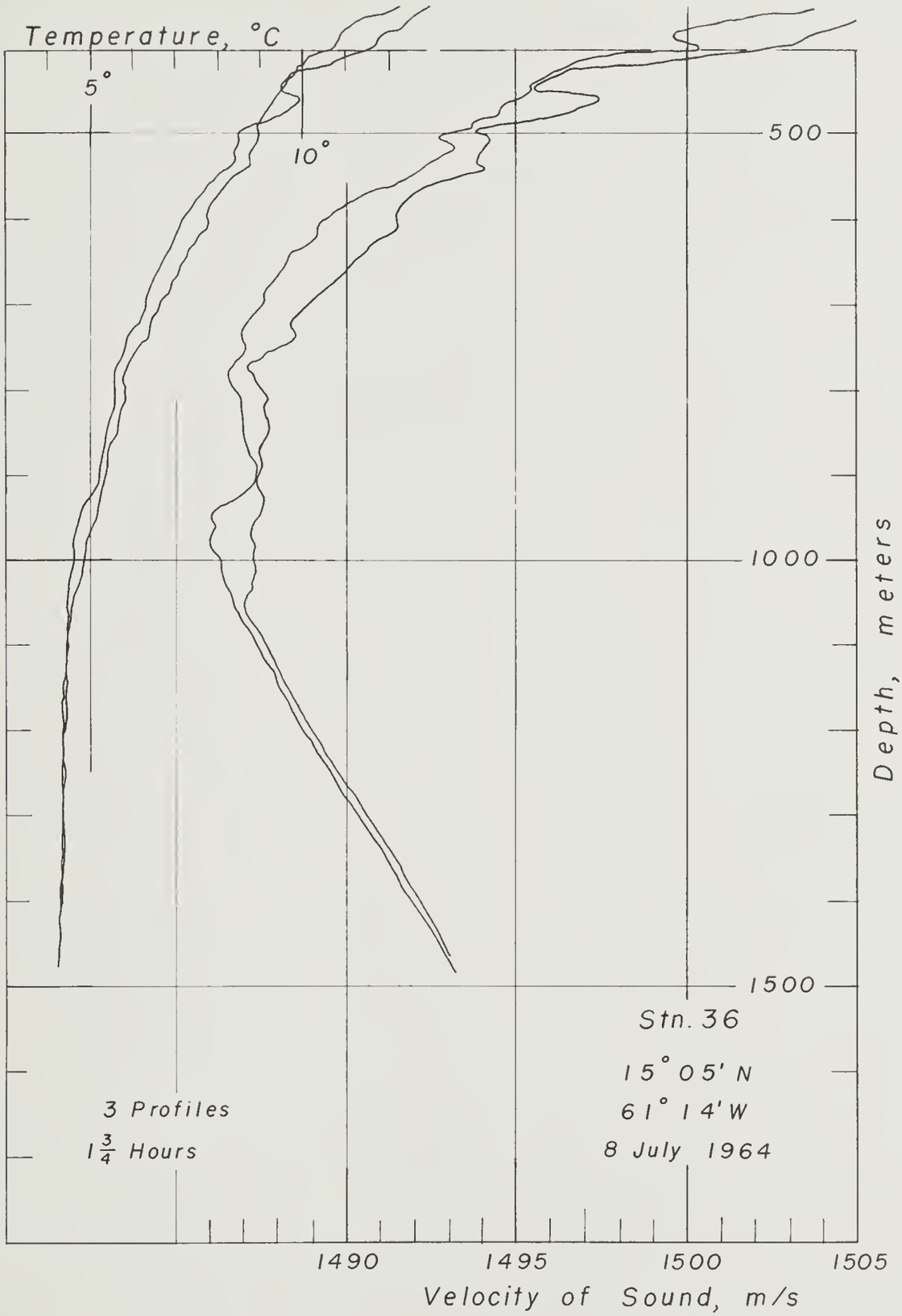

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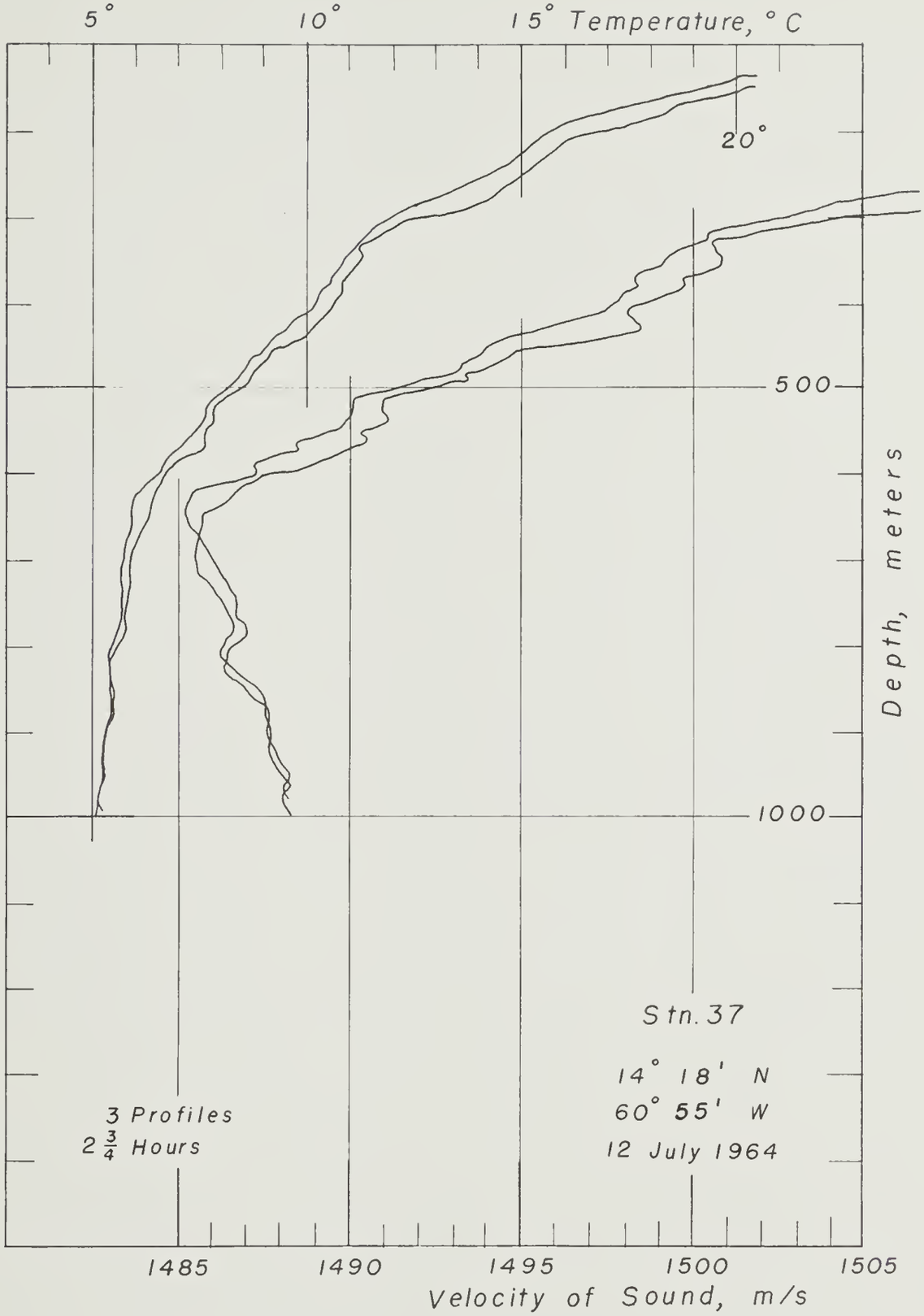

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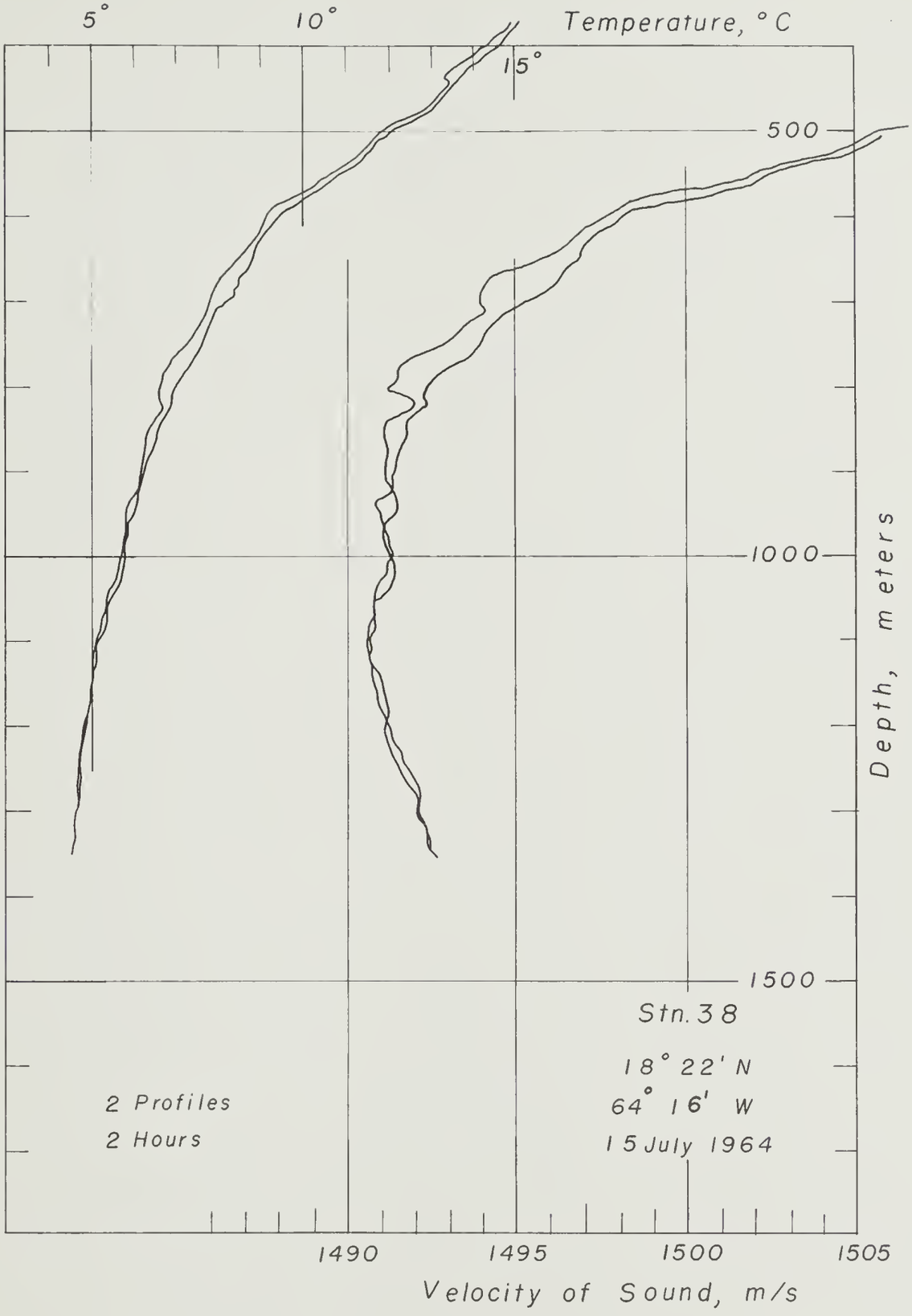

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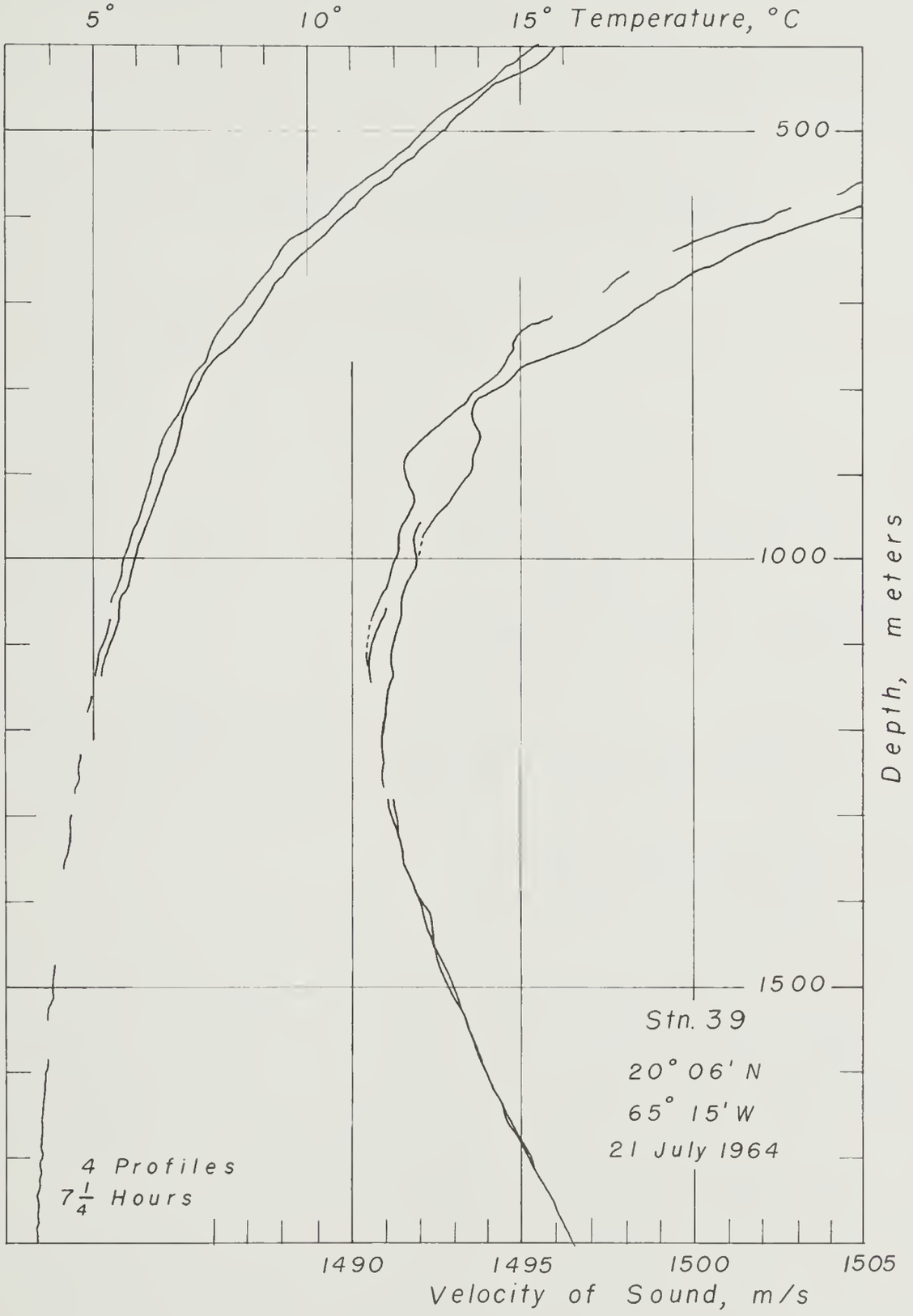

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A collection of consecutive, detailed sound velocity profiles from 20 stations in the Bermuda-Barbados-Puerto Rico area is presented together with composite profile envelopes of sound velocity, and temperature for each station. These stations were taken during the months of April to July. The report emphasizes the variability of the sound channel, and its dependence on geographical location. A number of cell-like water masses, differing from the norm at the site, are pointed out. Since a number of stations included in this report were taken at sites investigated during a cruise 4 months earlier, a comparison of the sound channel parameters for November-December and April-May is included. The 4-month changes at these sites are found to be of about the same order of magnitude as short-term variations over each station alone.
This report is a direct sequel to VOLUME I. of this series.(U)

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